EFFECT OF MOORING CONFIGURATIONS ON MOTION RESPONSES OF THE H-TYPE FLOATING BREAKWATER (H-FLOAT) IN RANDOM WAVES

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Dissertation submitted in partial fulfilment of
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CERTIFICATION OF APPROVAL

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Approved by,

(Dr. Teh Hee Min)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

(Wan Syazwani binti Wan Zulkifli)

ABSTRACT

This study focuses on the effect of mooring configurations of the H-Float in random waves. Laboratory tests were conducted with the aim to investigate the effect of mooring configurations on motion responses of the H-Float in random waves and to compare the motion responses of the H-Float moored by taut leg and catenary systems. The study of hydrodynamic responses of the H-Float in random waves is crucial as the test environment resembles the irregularity of the real seas. This study focuses only on the heave, surge and pitch movements, whilst the other motion responses were restricted. In order to quantify the motion responses of the H-Float, the Response Amplitude Operator (RAO) was utilized in the study. The RAO values for heave, surge and pitch obtained in the study will provide an insight on the extent of the movement of the H-Float subjected to various wave conditions. The results show that the motion responses of the H-Float are heavily affected by the mooring configurations and the wave period. The recorded RAO values show that the motion responses of the H-Float moored by taut leg system indicates lower RAO values of the heave, surge and pitch compare to the H-Float moored by catenary system. The peaked heave and surge RAOs for taut leg decreased with an increase of the B/L. Conversely, the surge RAOs for the catenary system increased with an increase of the B/L while the heave RAOs decreased with an increase of the B/L. However, the pitch RAOs for both mooring configurations carried no specific pattern with the changes in the B/L and wave periods. It is rather scarce and less predictable.

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CHAPTER 1

INTRODUCTION

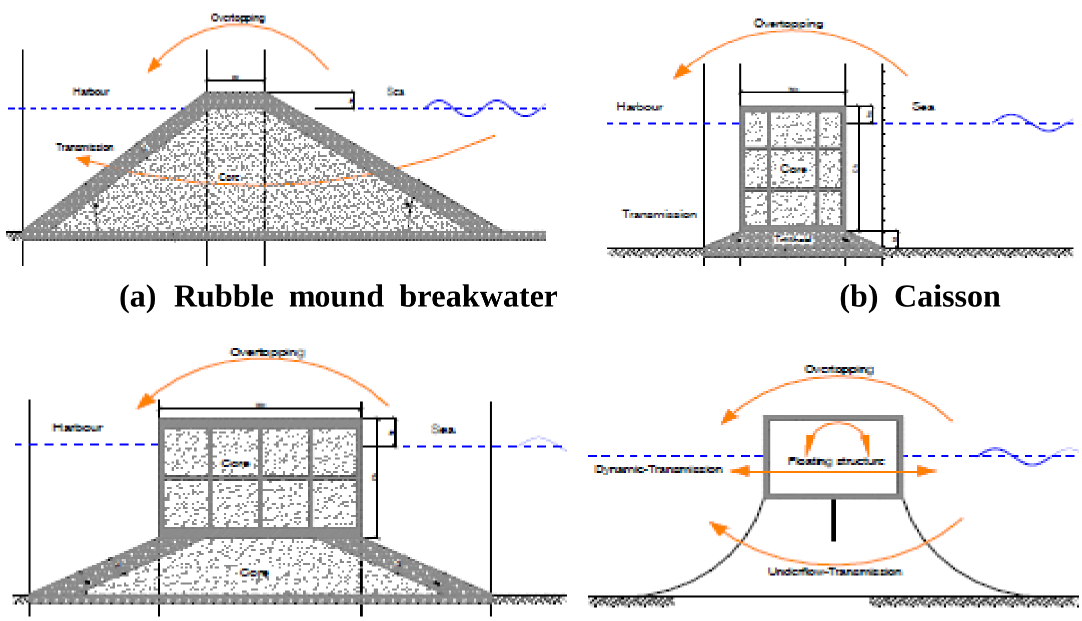
1.1 Background of study

In many cases fishing harbours, marinas, and aquaculture operations are partially protected from wave action by natural topographic features such as islands, spits, and shoals. However, due to the minimal fetch and wind speeds required to generate water waves of a magnitude large enough to limit such operation, most such sites require additional protection. Therefore, the natural wave protection found at a site is often augmented by the construction of a breakwater.

The basic purposes of breakwater is to protect a part of shoreline, a structure, a harbour, or moored vessels from extreme incident wave energy. Breakwaters can be classified as either fixed structures or floating structures. Both fixed and floating breakwaters are passive systems which means that no energy is produced by the device to achieve wave attenuation. The incident wave energy is either reflected, dissipated, transmitted, or subjected to a combination of these mechanisms. The construction of breakwaters reduces wave energy, by creating a shadow zone behind the breakwater, thus acting as a guard to other shoreline structures. Breakwaters are constructed to provide a calm basin for ships and to protect harbour facilities. Besides that, they are also used to protect the port area form the intrusion of littoral drift.

Floating breakwaters present an alternative solution to conventional fixed breakwaters. Poor foundation as well as environmental requirements, such as phenomena of intense shore erosion, water quality and aesthetic considerations have leads to the application of floating breakwaters. The application of a floating structure for the wave attenuation was first considered by Joly (1905). The U.S. Army Corps of Engineers (COE) has a potential requirement for a floating breakwater system to provide partial protection to dredges and work boats involved with the construction of coastal engineering features in the nearshore zone and on exposed coastlines with similar wave climates.

Permanently fixed breakwaters (rubble-mound or precast units) provide a higher degree of protection than floating breakwaters, however, they are very expensive to construct. According to McCartney (1985), it is often uneconomical and impractical to build a fixed breakwater in water deeper than about 20 feet as the construction cost of the breakwater is proportional to the square of water depth. Floating breakwaters provide less protection, but they are less expensive and are transportable from one location to another as required. It may be relatively easy to fabricate a floating breakwater at a site where a rigid bottom-resting gravity structure would be completely unstable foundation conditions.



(a) Rubble mound breakwater (b) Caisson

(c) Composite breakwater (d) Floating

breakwater

Figure 1.1: Several Breakwater Structures (Fousert, 2006)

Several major points exist in the consideration of a floating breakwater. The cost of a floating system is only slightly dependent on water depth and foundation conditions. While the construction cost of a fixed rubble-mound breakwater increases exponentially with depth, a floating breakwater requires essentially the same structural features regardless of the water depth. The interference of a floating breakwater with shore processes, biological exchange, and with circulation and flushing currents essential for the maintenance of water quality is minimal compared to fixed breakwater. The layout can be changed to accommodate changes in either seasonal or long-term growth patterns. Floating breakwaters appear to have greater multiple-use potential than fixed structures.

However, floating breakwaters have some disadvantages which must be weighed in their evaluation. The design of a floating breakwater system must be carefully matched to the site conditions, with due regard to the longer waves which may arrive from infrequent storms. The floating breakwater can fail to meet its design objectives by transmitting a larger wave than can be tolerated without necessarily suffering structural damage. Uncertainties in the magnitude and types of applied loading on the system, and lack of maintenance cost information, dictate conservative design practices which naturally increase the initial project cost. Therefore, a further research on the design optimization of the floating breakwater should be done in order to increase the performance of the floating breakwater.

1.2 Problem Statement

H-type floating breakwater was developed in 2005 in the endeavour to meet a wave protection issue with a functional cost-effective engineering design. Preliminary studies showed that it was capable of attenuating the incident wave height up until 80%. It is worthwhile to note that the floating breakwater was tested using a small scale experiment which was subjected to the following drawbacks:

i) <u>Limited test cases conducted in preliminary experiments, particularly in random waves.</u>

Due to the limitation of study in the field, especially in the case of mooring configurations that are opted to be used in the study, there are limited numbers of references that can be used to compare the results of the test. Thus, this may limit the validity of the testing results, as there are limited benchmark values that can be used.

ii) Inability to draw an absolute conclusion based on the limited measured data.

Wave hydrodynamics is a very subjective subject, in which the quantification of the wave hydrodynamics, either the motion or the forces acted on the breakwater due to the wave movement need be studied with a proper mechanism. The available measuring technique is subjected to errors due to manual observations and individual preferences. The limitation on the measuring equipment also might become a limitation in obtaining a more accurate result

iii) Significant pitch motion when subjected to wave attack.

The previous experiments done by the seniors shows that there are significant pitch motion towards the breakwater when subjected to the wave attack. This motion is due to the instability of breakwater test model. Therefore, some enhancement should be done in order to minimise the motion induce by the breakwater during the wave attack.

iv) Poor understanding of hydrodynamics and motion responses of the breakwater

A study of energy dissipations and movements of the breakwater due to the respond from the wave movement upon the breakwater is a wide field of study. Thus, it is important for us to tackle the basic studies and have the main ideas on how does the system works. A lack in this field of study might affect our judgment in providing good final findings

The present research is aimed at attempting the above mentioned limitations of the previous experiments. It is hoped that the research work carried out could provide greater insight on the hydrodynamics performance of the floating breakwater under various sea conditions.

1.3 Objectives of the study

The objectives of this study are as follows:

i. To investigate the effect of mooring configurations on motion responses of the H-Float in random waves via physical modelling.
ii. To compare the motion responses of the H-Float moored by taut leg and catenary systems.

1.4 Scope of study

There are several elements have been listed in the scopes of study in order to achieve the objective which are:

1. Literature survey

    - A comprehensive study of the behaviour of irregular waves will be discovered under this research. Several parameters involves under irregular waves will be listed in this study. Apart from that, the performance of floating structures subjected to irregular waves and also the wave spectrum that will be considered under this research will be explored. Some existing investigation of the floating breakwater through the journal paper and also conference paper in the past by different specialists was utilized as references. The different sorts of arrangement of the breakwater and their consequent impacts were given a genuine consideration from the studies since this criterion is basic before experiment can be conducted.

2. Enhancement of the breakwater design

    - Some potential improvement are identified to the proposed floating breakwater design in order to improve the motion responses as well as the overall hydraulic performance of the breakwater. The geometrical and hydraulic properties of the breakwater are to be determined. Construction materials are proposed to stimulate both geometrical and dynamic properties of the newly proposed floating breakwater. A ballast tank is to be designed within the breakwater so as to provide arbitrary immersion depths by filling the tank with water/sand. The test model must be waterproof and has high resistance to wave impact.

3. Fabrication of the breakwater models and the mooring systems

    - The H-Float model of scale 1:15 is to be constructed and moored by two different mooring configurations which is taut leg and catenary systems. Criteria with regards to mooring line forces are established. Additional number of mooring lines are introduced in order to minimise the significant pitch motion based on the previous experiment. H-frame system is introduced in order to avoid the damage of the test model.

4. Laboratory set-up

    - All equipment and apparatus involved in the experiment have to be calibrated with care so as to prevent systematic error during measurements. These measurement equipment include optical tracking system and wave probes. The wave-structure interactions and underwater activities will be captured by a water-proof still camera and a video-camera.

5. Laboratory tests

    - Numerous laboratory tests are to be carried out in order to quantify the hydrodynamic behaviour of the test models. Some of the dependant variables considered in this study is wave heights, wave periods and mooring configurations. The efficiency and practicality of the proposed floating breakwater are evaluated based on the results gained from the laboratory tests.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses the background information regarding the ocean waves and also the fundamental concepts on the hydrodynamics of a floating structure. The criteria and parameters that subjected to irregular waves are discovered under this chapter. Besides, some basic types of floating breakwater are also introduced under this chapter. Apart from that, the chapter will measure up all the past outcomes of that related to floating structures and attempt to identify the significance of each studies that have been carried out by the researches. These outcomes will be the foundation and will go about as the benchmark of our studies.

2.1 Background Information on Ocean Waves

Waves on the surface of the ocean are primarily generated by winds and are a fundamental feature of coastal regions of the world. Knowledge of the waves and the forces is essential for the design of coastal projects since they are the major factor in determining the geometry and composition of beaches and significantly influence the planning and design of marinas, waterways, shore protection measures, hydraulic structures, and other civil and military coastal works. Estimates of wave conditions are needed in almost all coastal engineering studies.

Surface waves derive their energy from wind, and a significant amount of this energy is dissipated in the nearshore region. The wave energy shapes the coastline, transports and sorts bottom sediments, and exerts forces on coastal structures, hence the information obtained from wave climate data is important for planning and design in coastal and offshore engineering. According to study done by Lemm (1996), the local wave climate is also important in other fields, such as shipping, commercial fishing, coastal research and recreation.

Wind-generated waves are important since the waves first obtain energy from wind and then transfer the energy across the expanse of the ocean to the coastal zone. A spectrum of ocean surface waves proposed by Kinsman (1965) is depicted in Figure 2.1, and it suggests that wind-driven waves contribute the largest amount of the energy from the ocean to the beach and nearshore physical system. In particular, surface gravity ocean waves with periods between 3 and 25 s are the major influence on the geometry of beaches, planning and design of coastal works (USACE 2002). Therefore, there is an importance to gain an understanding of these waves and the associated generated forces for the planning and design of coastal projects.

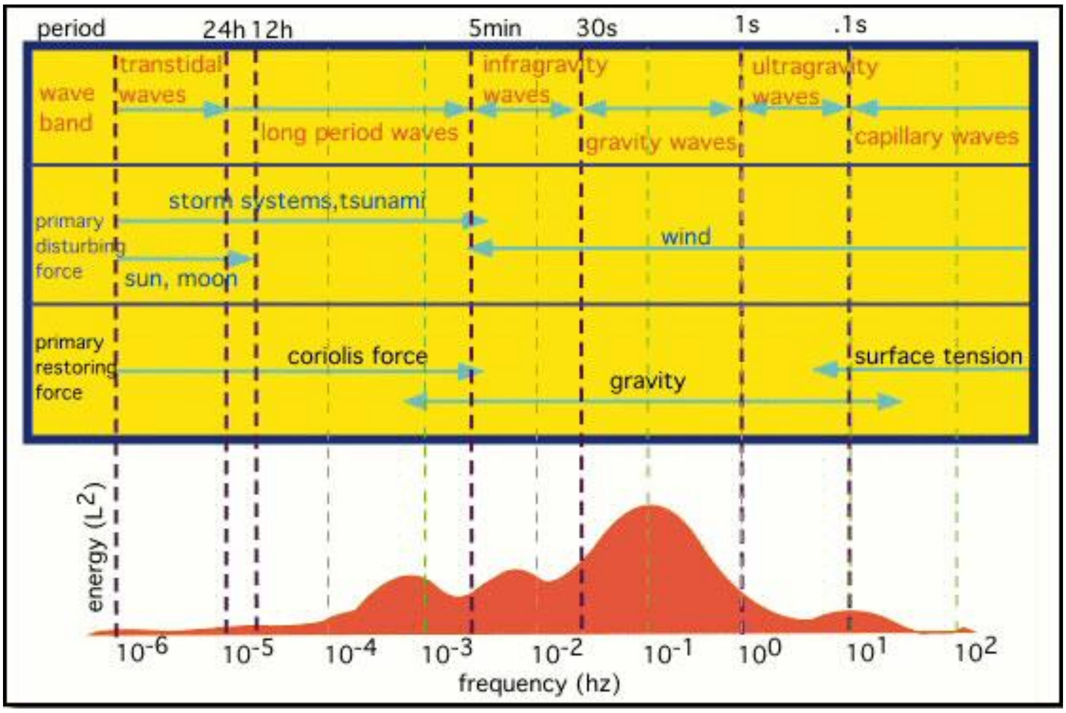


Figure 2.1: Distribution of the ocean surface wave energy (Kinsman 1965)

2.1.1 Classification of Ocean Surface Waves

The classification of progressive waves propagating on the ocean surface is usually based on wave period T or frequency f. It is important in coastal practice to differentiate between two types of surface waves which consists of seas and swells. Seas refer to short-period waves still being created by winds while swells refer to waves that have moved out of the generating area. Table 2.1 below listed the criteria belongs to both seas and swells.

Seas	Swells
i. Short-period waves created when the wind blows on the surface of the water. ii. More disturbed sea surface with choppy waves of mixed wavelengths and different wave heights. iii. Irregular waves with short-crested. iv. Periods are within 3-25sec. v. Waves of high steepness and short wavelength (L=10-20 hours). vi. Present if windy. vii. Propagate in the wind direction.	i. Waves that are moved out of the generation/storm area. ii. Waves are in more orderly state with definite crests and troughs. iii. Regular waves with well-defined long crests. iv. Relatively long periods (greater than 10 sec). v. Waves of mild steepness and long wavelengths (L=30-500 hours). vi. Present even with no wind. vii. Propagate in groups.

Table 2.1: Comparison between Seas and Swells

2.2 Theories and methods of wave analysis

2.2.1 Irregular Waves

In the open ocean, it is impossible to keep track on each individual wave. The ocean surface is often a combination of several wave components that were individually generated by wind in different regions and have travelled to the observation point. Hence real wave systems would be irregular and random, and incorporating many superimposed components of different wave periods, heights, and directions. Therefore, as waves are random, a statistical approach is often used to define design conditions. There are two methods involves in treating irregular waves which is time domain analysis and frequency domain analysis.

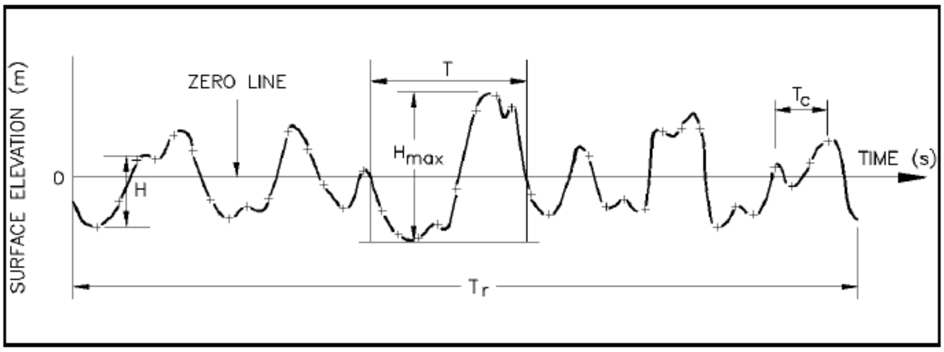


Figure 2.2: Wave parameters for an irregular sea state

2.2.2 Time Domain Analysis

The wave-by-wave analysis determines wave properties by obtaining the average statistical quantities of heights and periods of individual wave components (USACE 2002). The undulations of the water surface from the mean water level are manually identified as individual wave using the zero-downcrossing method to obtain representative wave parameters, and using this information, statistical characteristics of the wave record can be estimated and statistics of the record are compiled (USACE 2002). Wave height is the vertical distance between the highest and lowest points between two successive zero-downcrossing.. All the local maxima and minima not crossing the zero-line is discarded.

This time-domain method requires direct measurements of sea surface, and the wave records must be sufficiently large to obtain reliable statistics. The primary disadvantage to the wave by- wave analysis is that it does not give an indication about the direction of the waves; therefore a single wave at a point may actually be the local superposition of two smaller intersecting waves from different directions (USACE 2002).

One of the most common time domain analysis that can be used to extract wave characteristics from time series is zero-crossing method. Individual waves are determined by this method. Each wave is defined as the water level elevation variation between two successive up crossings of the time series relative to the zero elevation. Wave defined by the upcrossing method are composed of a wave crest then followed by a trough. Wave height is taken as the total vertical distance between the wave crest and wave trough.

2.2.3 Frequency Domain Analysis

Frequency-domain analysis is widely used in such areas as communications, geology, remote sensing, and image processing. This analysis shows how the signal's energy is distributed over a range of frequencies. A frequency-domain representation also includes information on the phase shift that must be applied to each frequency component in order to recover the original time signal with a combination of all the individual frequency components.

This analysis utilises Fourier theory to transform the irregular ocean surface into a summation of simple sine waves, and wave characteristics are defined in terms of its spectrum. The wave spectrum denotes which frequencies have significant energy content. The distribution of the variance is defined with frequency as S(*f*), assuming that the function is continuous in frequency space. The function E(*f*) is often called the frequency energy spectrum, and is defined as

$$\boldsymbol{E = \rho g \int_0^\infty S(f)df} \qquad \textbf{Equation 2.1}$$

where is the seawater density and g is the gravitational acceleration (Tucker and Pitt 2001).

The following points outline some of the benefits of applying the frequency domain analysis method:

i. The approach is easily implemented on microchip and packaged with gauging instrument
ii. The spectral theory is the basis for principal successful theories for describing wave generation by wind and modelling evolution of natural sea states in coastal regions

iii. It is currently the only widely used approach for measuring wave direction

iv. Fourier/spectral analysis of waves has large technical literature and statistical basis that can be readily drawn upon.

In essence, any unidirectional sea state can be described mathematically as being composed of an infinite series of sine waves of varying amplitude and frequency. Thus, the surface excursion at any time may be represented as:

$$\boldsymbol{n(t) = \sum_{n=1}^{\infty}[\alpha_n \cos \omega nt \ + \ b_n \sin \omega nt]} \qquad \textbf{Equation 2.2}$$

where ω is the angular frequency (2π/T) and t=0 to t=T; a_n and b_n are amplitudes.

$$\boldsymbol{n(t) = \sum_{n=1}^{\infty} c_n \cos(\omega nt + \emptyset_n)} \qquad \textbf{Equation 2.3}$$

where:

$$\boldsymbol{{c_n}^2 = {a_n}^2 + {b_n}^2} \qquad \textbf{Equation 2.4}$$

$$\boldsymbol{\tan \emptyset_n = \frac{-b_n}{\alpha_n}} \qquad \textbf{Equation 2.5}$$

Noting that the equation for wave energy is E=ρgH^2/8, the wave energy is proportional to H^2 (with units of m^2), thus the spectral energy density curve *S*(*f*) (with units of m^{2}s) may be found from

$$\boldsymbol{s(f)\Delta f = \sum_{f}^{f+\Delta f} \frac{1}{2} {c_n}^2} \qquad \textbf{Equation 2.6}$$

where c_n can be determined by the Fast Fourier Transform (FFT).

$$\boldsymbol{T_{m1} = \frac{m0}{m1}} \qquad \textbf{Equation 2.7}$$

$$\boldsymbol{T_{m02} = \left(\frac{m0}{m2}\right)^{0.5}} \qquad \textbf{Equation 2.8}$$

$$\boldsymbol{m_n = \int_0^{\infty} s\,(f)\,df} \qquad \textbf{Equation 2.9}$$

2.2.4 Significant Wave Height and Peak Period

The concept of significant wave height H_s or $H_{1/3}$ is a very useful and important index to characterise the heights of the surface waves on the sea. Kinsman (1965) has defined the significant wave height as the average height of the one third highest waves in a sample record. This is measured because the effects of larger waves are usually more significant than the smaller waves. Besides, significant wave height is used to correlate very well with the wave height a skilled observer perceives in a wave spectrum.

The mean period of these 'significant' waves is termed as the significant wave period T_p. According to Kinsman (1965), visual observations of wave heights and periods are good approximations of H_s and T_p. Peak period, T_p, is the reciprocal of the frequency at which the peak of the spectrum occurs (Tucker & Pitt 2001). T_p is associated with the largest wave energy and is only obtainable through spectral analysis.

$$\boldsymbol{H_s = H_{m0} = 4(m0)^{0.5}} \qquad \textbf{Equation 2.10}$$

where *m0* is the spectral moment or variance (energy) of sea surface elevation given by

$$\boldsymbol{m_0 = \int_0^\infty s\,(f)\,df} \qquad \textbf{Equation 2.11}$$

$$\boldsymbol{T_p = \frac{1}{f_p}} \qquad \textbf{Equation 2.12}$$

where f_p is the frequency at the maximum value of the spectral energy density curve, S(f)

2.2.5 Wave Spectrum

Wave power is defined as the rate of energy transmission in the direction of wave travel across a vertical plane that is perpendicular to the direction of wave propagation and extending down the entire depth (USACE 2002). For a unidirectional wave spectrum, the power transported per metre of the crest length can be derived using spectral energy (Tucker and Pitt 2001):

$$P = EC_n = \rho g \int C_g(f) S(f) df$$ **Equation 2.13**

where C_g is the group velocity, which is defined as the rate of transmission of wave energy:

$$C_g = C_n$$ **Equation 2.14**

E is termed the specific energy and is the total average wave energy per unit surface area:

$$E=\rho g H^2/8$$ **Equation 2.15**

n = 0.5 in deep water, increases in value in the transition zone to become n= 1 in shallow water.

2.2.5.1 JONSWAP Spectrum

Hasselmann et al. (1973), has analysed numerous data collected during the Joint North Sea Wave Observation Project (JONSWAP) and he has found that the wave spectrum is never fully developed. It continues to develop through non-linear, wave-wave interactions even for very long times and distances. Hence an extra and somewhat artificial factor was added to the Pierson-Moskowitz spectrum in order to improve the fit to their measurements. The JONSWAP spectrum is thus a Pierson Moskowitz spectrum multiplied by an extra peak enhancement factor γ^r .

$$S(f) = \frac{\alpha g^2}{(2\pi)^4 f^5} exp\left[-1.25\left(\frac{f}{f_p}\right)^{-4}\right]\gamma^{exp\left(\frac{\left(\frac{f}{f_p}-1\right)^2}{2\,\sigma^2}\right)}$$ **Equation 2.16**

$$\alpha = 0.076\left(\frac{gF}{U_{10}^2}\right)^{-0.22}$$ **Equation 2.17**

$$f_p = \frac{3.5g}{U_{10}}\left(\frac{gF}{U_{10}^2}\right)^{-0.33}$$ **Equation 2.18**

γ = the peak enhancement parameter ($1 < \gamma < 7$; with an average value of 3.3)

2.3 Floating Breakwater

Floating breakwater offer an alternative to conventional fixed breakwaters in coastal areas with mild wave conditions. The main function of floating breakwater is to attenuate waves to an acceptable level. Compared to fixed breakwater, the floating breakwater would minimize both reflection and transmissions by allowing some water to pass below the structure while the fixed breakwater restricting the water to pass through. Such a structure cannot stop all the wave action. The incident wave is partially transmitted, partially reflected, and partially dissipated. Kuotandos et. al., (2004) stated that energy is dissipated due to damping and friction through the generation of eddies at the edges of the breakwater. It creates a sheltered region in order to prevent damage to shorelines, harbours, and other natural and man-made structures.

2.3.1 Types of Floating Breakwater

The types of floating breakwater available depends on the combination of materials, breakwater shape, its mooring system (including configuration) and its function (Lee, 1999). According to McCartney (1985), there are four general types of floating breakwaters:

<u>(1) Box type floating breakwaters</u>

Kurum (2010) stated that box type breakwaters are the most frequently used as alternative to the fixed breakwaters due to the more economical, environmental and economic friendly compare to the conventional breakwaters. They are usually made up of reinforced concrete, rectangular-shaped modules that may be flexibly or rigidly connected to other modules to make a larger breakwater and also of steel or even barges. They generally act as barges, which dissipate energy at the wave surface. This type of breakwaters are numerous and include a fifty-year design life, proven performance, simple construction and effectiveness under moderate wave condition. However, the major disadvantages of the box type breakwaters are its relatively high cost compare to other types of floating breakwaters and require higher maintenance.

(2) Pontoon type floating breakwaters

The ladder type, catamaran type, sloping-float (inclined pontoon), and a frame type are the examples of pontoon types floating breakwater. Pontoon types have similar advantages and disadvantages to the box type but less expensive than box. Important parameter to be given attention is to the L/B parameter as it was in the box type (McCartney, 1985). Other usages of these types of structures are for floating walkways, storage, boat moorings, and fishing piers (Hales, 1981).

(3) Tethered float

Tethered floating breakwater type is seldom used and quite different from other types of floating breakwater. Rather than attenuate waves by using their mass, the tethered floating breakwater uses its mooring system to dissipate wave energy. Waves move the breakwater around until the mooring system restricts its motion, then wave energy is transferred to the anchors and ultimately the sea floor, dissipating the wave height. Mays (1997, 1999) has performed work involving this type of breakwater; although thus, this type of breakwater is still under investigation and there is not a significant amount of information on these moored breakwaters to make any conclusive remarks.

(4) Mat

Tire mat breakwaters consist of three basic designs such as Wave Maze, Goodyear, and Wave-Guard (Hales, 1981). DE Young (1978) and McCartney (1985) in their paper discussed about the advantages and disadvantages of these structure. Advantages of the tire mat breakwater are low cost, simple design and construction, portability, low anchor loads, and greater effectiveness than box and pontoon types while the disadvantages include lack of buoyancy, 15-20 year design life, they do not effectively damp long wave lengths, they cannot be moored year round because of icing effects, and they can break apart if not constructed adequately and then they would create floating debris.

Some examples of floating breakwaters are listed in table below:

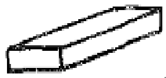
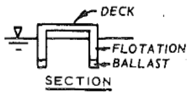
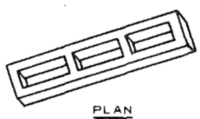
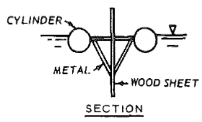
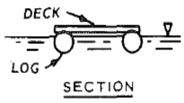
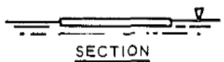
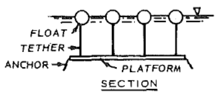
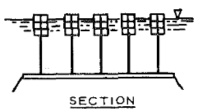
TYPE	VIEW	REMARKS
<u>BOX</u>		
SOLID RECTANGLE		Reinforced comcrete units are the most common type
BARGE		Standard barge sizes on inland waterways are 195' x 35' x12' and 175' x 26' x 11'. Inclined barges (one end submerged have been tested)
<u>PONTOON</u>		
TWIN PONTOON		Catamaran shape
OPEN COMPARTMENT		Also called Alaska type
A FRAME		
TWIN LOG		Deck is open wood frame
<u>MAT</u>		
TIRE MAT		Scrap tires strung on pole framework or sound together with chain or belting. Foam flotation is usually needed.
LOG MAT		Log raft chained or cabled together
<u>TETHERED FLOAT</u>		
SPHERE		Floats placed in rows
TIRE		Arrangement similar to spheres. Steel drums with ballasts can be used in lieu of tires.

Table 2.2: Types of Floating Breakwater (McCartney, 1985)

2.3.2 Patents of Floating Breakwater Design

According to the invention done by Matsudaira and Mishina (1976), a floating breakwaters comprises a float, a front and rear barrier, and anchor cables or chains so that the floating breakwaters are simple, yet rigid in construction and inexpensive to manufacture, and have the excellent wave attenuating capabilities as shown in figure 2.3. The high energy of the onrush wave closer to the surface of the sea is effectively reflected by the front barrier, and the major portion of the remaining wave advances below the front barrier while the minor portion overrides the front barrier. The energy of the major portion advanced below the front barrier is distributed to the surface of the sea so that it may be effectively reflected and dissipated by the center float. This invention may minimized the motion of pitching, heaving and surging induce by the floating breakwater, and the waves of a relatively wide range of wave lengths may be effectively reflected and abated so that a safe and calm sea space may be provided at the lee side of the floating breakwater.

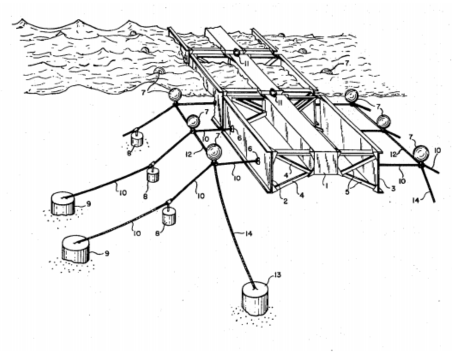


Figure 2.3: FBW comprises of float and barriers (Matsudaira and Mishina, 1976)

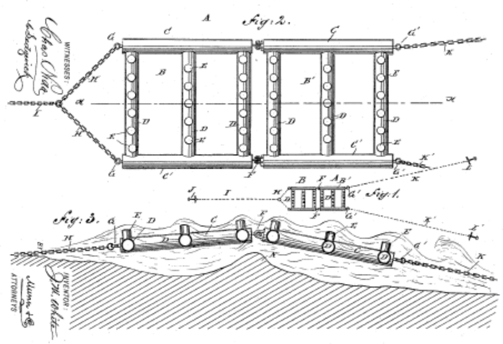


Figure 2.4: Series of pontoons pivotally connected with each other (White,1890)

White (1890) invented a new and improved floating breakwater, which is simple and durable in construction. This floating breakwater as shown in figure 2.4 was specially designed for the protection of coasts by overcoming the action of larger waves in completely breaking their force before they reach the shoreline. The invention consists of a series of pontoons pivotally connected with each other, and each composed of longitudinal and transverse hollow cylindrical tubes, and projections extending upward from the side tubes.

2.3.3 Hydrodynamic Behavior of Floating Breakwater

There are a lot of research has been done on the hydrodynamics behavior of floating breakwaters. The major focus of all these studies has always been to obtain small amount of transmission coefficients. The transmission coefficient is the ratio between the wave heights at the leeward (harbor) side of the floating breakwater relative to the incident wave height. In order to obtain satisfactory results, many designs were model-tested. The major aspects of the structural design that have been tested:

a. Shape;
b. Width of the floating section of the structure;
c. Draft of the structure;
d. Mass of the structure;
e. Permeability of the structure.

All these structural factors influence the (hydro) dynamic behavior of the floating breakwater. A heave motion floating breakwater will perform better when it is not affected in its vertical degree of freedom (Silander, 1999). However, sway motion will give a negative contribution on the attenuating capacity of the floating breakwater. In his study, Silander (1999) also proved that a free motion floating breakwater performs better at a certain frequency range when the structural width is optimal.

Apart from that concluded by Silander (1999), the effect of surge, heave and pitch motions on the performance of a floating breakwater also was studied and it was

concluded that the surge motion of the model is the major contributor to wave transmission (Sutko and Haden, 1974).

While the draft and the mass of the structure are related to one another when the structural width is kept constant. Tolba (1999) concludes that increasing the draft with a screen has a positive effect on the wave transmission.

2.4 Types of Mooring

Mooring denotes to the way the floating breakwater is anchored to the seabed by means of using a line to lock up the movement of the floating breakwater. The primary purpose of a mooring system is to maintain a floating structure on station within a specified tolerance. There are several types of mooring configurations that are commonly used for floating breakwater applications, such as the catenary moorings, taut-leg moorings, pile moorings, hinged moorings, and taut-line with spring support

2.4.1 Catenary Moorings

Catenary mooring is one of the conventional ways of connecting the taut line to the floating breakwater. Catenary mooring consists of a mooring line, connected to the anchor or a pile stake, located at the bottom of sea bed. In this type of mooring system, some part of the mooring line lay on the bed of the sea. Given this condition, the tension of the line is higher than the weight of the submerged line itself, as being described in the study by Nielsen and Bidingbo (2000). The illustration of such configuration is described in **Figure 2.4**, in which some part of the mooring line is shown laying at the bottom of the seabed

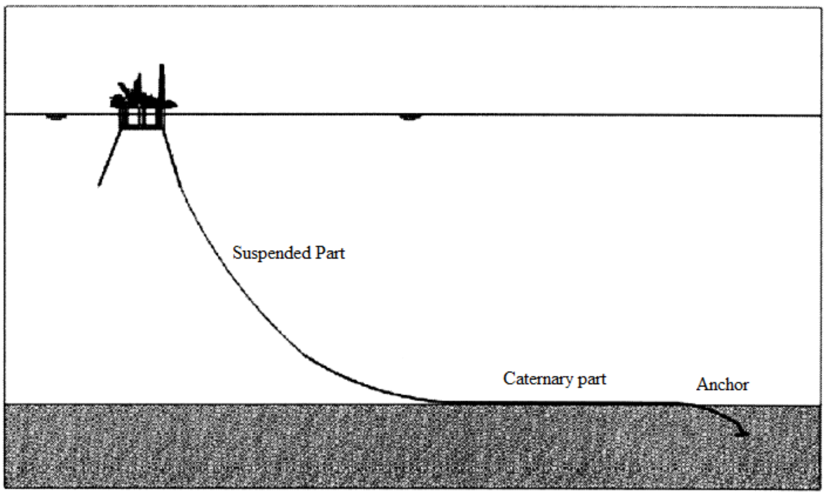


Figure 2.5: Catenary mooring system (Source: Nielsen and Bidingbo, 2000)

The catenary mooring system is the most common mooring system used in the floating breakwater applications. The length of the catenary line must be longer than the depth of the water, as some of the line needs to be horizontally laid on the seabed. Due to this condition, the mooring lines only need to withstand the horizontal tension from the weight of the lines. However, this kind of mooring system is not suitable for deep water, as a longer line means a higher loading from the floating breakwater will act upon the mooring lines. Thus, as the water gets deeper, the less significant the usage of catenary mooring system will be

In the study done by Garza-Rios *et al* (1997), it is concluded that the horizontal tension of a catenary mooring line can be found by using the following formula:

$$\frac{T_o}{P}\sinh\left(\frac{Pl}{T_o}\right) = \sqrt{h\left(h + 2\,\frac{T_o}{P}\right)}$$

Where: T_o = Horizontal tension of catenary line

P = Vertical force unit per catenary length

l = horizontally projected length of the suspended portion of the catenary

h = water depth

The equation shows a relationship between the amount of horizontal tension of the catenary line and the length of suspended portion of the catenary. Based on the equation, it is understood that the horizontal tension decreases when the length of suspended catenary increases. This happens due to the presence of more vertical tension acting on the lines with respect to the suspended carternary lines.

2.4.2 Taut-leg Moorings

Another conventional way of connecting mooring line to the floating breakwater is the taut-leg mooring system. The taut-leg mooring system can be defined as a straight string of line connected directly from the anchor at the sea bottom to the floating breakwater. As far as the system goes, the mooring line attached is fully suspended, with no line resting on the sea bed, as opposed to the catenary mooring system, as described in the following **Figure 2.5**. Note that in the figure, the mooring line is completely suspended with no lines being rested on the seabed.

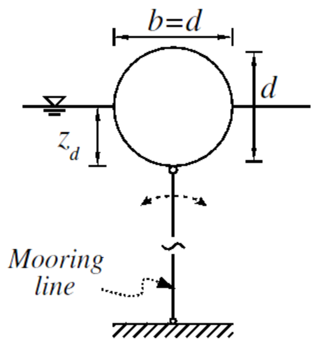


Figure 2.6: Taut Mooring system (Source*:* Ozeren *et al*, 2011)

Due to the suspended nature of the taut line system, it is subjected to both horizontal and vertical tension on the mooring line. The line can be attached either in a vertical direction or slightly inclined. Both these difference in ways of connecting the taut lines will have an effect to the instantaneous movement of the floating breakwater, as being studied by Rahman *et al* (2006). Based on the **Figure 2.6**, the response of the floating breakwater towards wave action differs depending on the way the floating breakwater is moored, either in a straight vertical direction or slightly inclined.

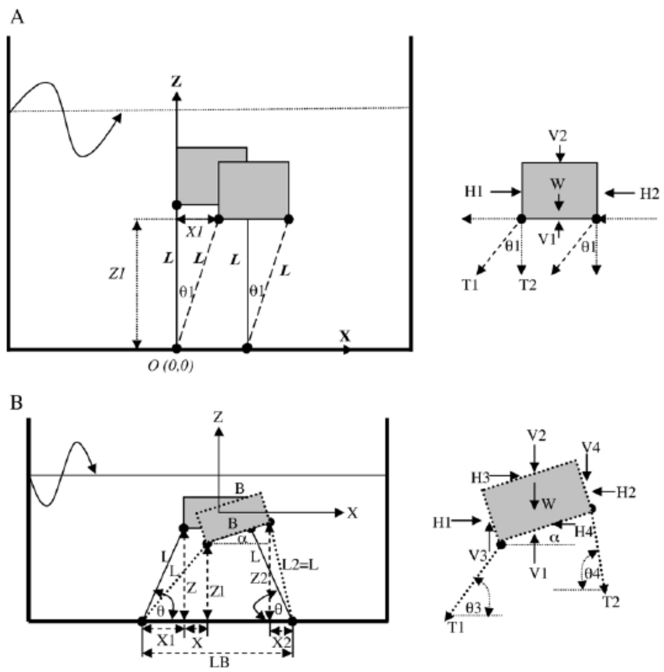


Figure 2.7: Instantaneous movement for submerged body for (A) Vertical moored body and (B) Inclined moored body (Source: Rahman *et al*, 2006)

Due to its ways of connection, taut-leg mooring system is most suitable to be used in a deep water condition. Furthermore, anchor type embedment is most suitable to be used with taut-leg system, as it provides more strength in terms of withstanding capability in handling the vertical and horizontal forces acting on the line. Due to this nature, the usage of synthetic lines is more advisable as compared to metal chains.

The effectiveness of the taut line is subjected to various factors that may affect the performance of the taut line and the breakwater as a whole. These factors will be discussed further in this chapter in order to understand their effects towards floating breakwater behaviour.

2.4.3 Pile Moorings

Pile mooring is one of the three most common types of mooring system used in the application of floating breakwater, as being proposed by McCartney (1985). In this system, the floating breakwater is hold onto its position by a set of pile moored into the bottom of the seabed. This type of mooring restrains the lateral movement of the breakwater, which allows the breakwater to move only in vertical axis direction. It is more suitable to be used in a shallow area due to its economical limitations. **Figure 2.2** illustrate the set up of pile moorings, with a set of piles is connected from the breakwater to the bottom of the seabed. The studies of application of piled mooring in floating breakwater were done by Mani and Jayakumar (1985) and Diamantoulaki *et al* (2009). Both studies indicate that the stiffness of the piled system plays an important part in the performance of the breakwater, as well as forces acted on the support itself.

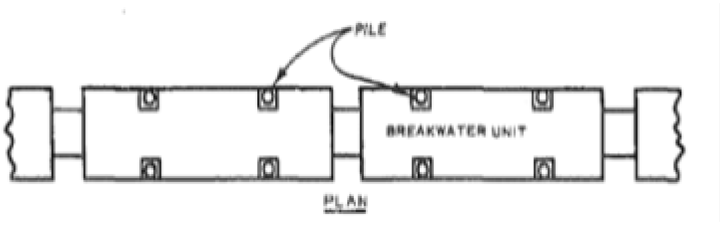


Figure 2.8: Pile-restrained floating breakwater

(Sources: Diamantoulaki *et al*, 2009)

2.4.4 Hinged Moorings

Apart from of those proposed by McCartney, Leach *et al* (1985) also proposed another mooring configuration for a floating breakwater, namely the hinged mooring. Hinged mooring uses the idea of a piled mooring system, with an additional hinged mechanism added at the bottom of the pile, as shown in **Figure 2.3**. The introduction of hinge at the bottom of the pile gives the pile the ability to incline itself when the wave hits. This system will give the floating breakwater more degree of freedom than of that in a pile mooring system. The hinged pile is held by mooring lines, as being illustrated in **Figure 2.3**. The incline-ability of the piles will help to reduce mooring forces acting on the lines. The application of using hinged moorings has been also supported by the study done by Diamantoulaki and Angelides (2010), which confirms the practicality of the hinged moorings.

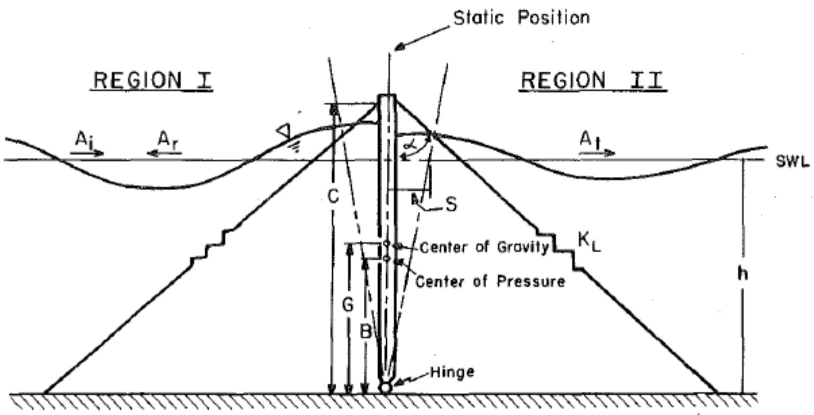


Figure 2.9: A hinge floating breakwater (Source: Leach *et al*, 1985)

2.4.5 Taut-leg with Spring Support

This mooring system is the least used in the real-life application of the floating breakwater. The insertion of spring or suspended materials will help to reduce the damping effects and impact loads on the mooring lines. Mavrakos *et al* (1994) and Chen *et al* (2001) have developed a study on the insertion of a spring in the mooring lines system. The purpose of adding the spring is to help to increase the overall stiffness of the mooring lines. The addition of the springs will help to increase the trajectory of the mooring lines, in which will help them to be able to withstand the forces acting on the mooring line. The addition of springs to the mooring line also helped when there are no suitable materials available in the market to adopt the required forces acted on the lines

There are many factors that may affect the performance of these mooring lines as a whole, and stiffness is one of the things that need to be considered. Thus, the introduction of the spring inside the mooring lines will give the mooring line extra advantage. The nature of the string will help to adjust the stiffness of the line accordingly, and thus, helps to maintain or adjust the stiffness of the line depending on the condition required.

2.5 Factors Affecting Hydrodynamics of the Floating Breakwater

As being mentioned in the previous chapter, there are some parameters that may affect the hydrodynamics behavior of the floating breakwater. The variability of these parameters may affect the hydrodynamics motion and forces of the floating breakwater, such as the heave, roll, moore tension and etc. Various studies and experiments has been done to determine the effect of such parameters and what are the optimum values of these parameters in order for us to get maximum efficiency of the floating breakwater.

2.5.1 Mooring Lines Materials

In the configuration of the mooring system by using lines, the type of lines that being used might affect the hydrodynamics behavior of the mooring line. The mooring lines is the material that connected the floating breakwater with the anchor at the sea bottom, in which holding the breakwater in its place. The suitability of the material that need to be used as the mooring lines are dependent on many factors, such as the elasticity and stiffness of the material, as well as the type of mooring configuration itself. The two common types of the materials that conventionally used are chains and synthetic lines.

a) Chain

Chain mooring line is made up of heavy steel and was used in most of the mooring line. Chains come in different grades and diameters, which will be used in different situations. Chains are preferably used in the catenary mooring line, in which some part of the lines need to lay on the sea bottom in order to give the line only horizontal force acting on it, as shown in **Figure 2.8**. Furthermore, chains are more preferable to be used for permanent moorings, as it gives the mooring line extra strength in withstanding the movement of the breakwater structures

Due to the heavy nature of the chains, it is not preferable to use the chains in the mooring line for a modern floating breakwater. The heavy nature of the chain caused some difficulties in installing the mooring system, especially in a deep water condition. While the usage of chain in mooring line might be a suitable material in the catenary mooring system, it is less preferable to be used in other kind of mooring systems, especially in the taut leg mooring system. The requirement of additional buoyancy in a taut leg system makes the mooring system using chain lines seem to be less preferable. The hydrodynamic behavior of a taut chain line, which may exert an extra vertical and horizontal force on the mooring line, makes this option less preferable. Thus, there is a need of having alternative options as far as the mooring line materials is concerned

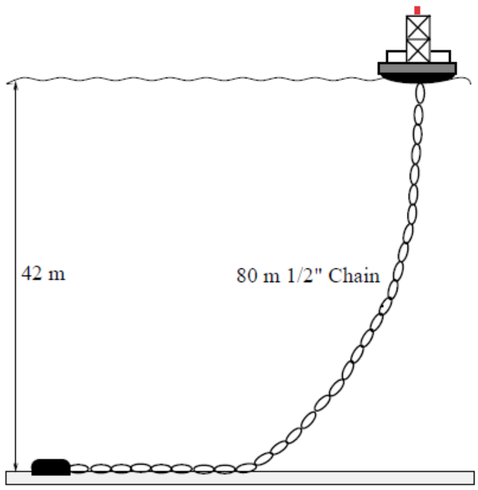


Figure 2.10: Chain mooring line for a catenary mooring

(Source: Gobat and Grosenbaugh, 2001)

b) Synthetic Line

In order to overcome the weaknesses of the chain lines, researchers have come up with another options as far as the mooring line materials is concerned, which is by using synthetic lines. Synthetic lines are cables that are made up of a set of materials with different composition in order to give the lines extra characteristics that can overcome the weakness of the chain mooring lines. The synthetic lines might be produced form a completely different materials, such as synthetic fibre, or a composition of two or more materials, such as in a polymer lines. The synthetic lines are more preferable in a straight vertical connection, such as the taut leg mooring system, as it does not exert too much pressure on the anchor in which can avoid the line to break loose from the anchorage bond, but in the same time, provide strength strong enough to withstand the vertical and horizontal tension. The characteristics of a mooring line can be modified accordingly, which gives the mooring line advantages to be used under various sort of wave and sea conditions.

Ridge (2009) has tested a few synthetic mooring lines of different materials and configurations in a study to test for the strength of different materials subjected to axial loading. Figure 2.9 denotes the result of the experiment. And based on the figure, it is known that the different composition of synthetic lines do behave differently, in which signals that the different type of materials do affect the performance of the mooring system accordingly

Apart from that, Tahar and Kim (2008) also tested a synthetic polymer line in order to compare the performance of such lines as compared to a normal synthetic line. Based on the study, it can be said that a polymer-enhanced synthetic lines do give an upgraded performance to the normal synthetic line up to a certain extend. Huang *et al* (2012) also tested a synthetic fibre line enhanced in a polyster case to check for the strength of such configuration. In the end of the study, it is found that the presence of polyster-case helps to increase the tension capability of a synthetic fibre line. This is important feature, as tension capability is important to ensure that the mooring line that we provide do not snap easily once it is exposed to the hydrodynamic forces acting on the line when it is being installed.

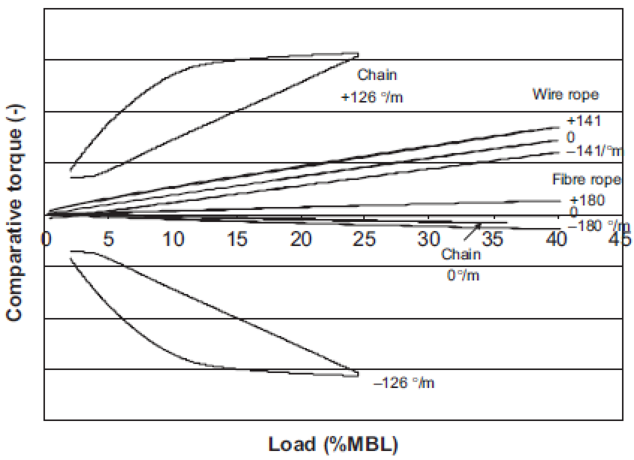


Figure 2.11: Torsional response of different lines under axial load

(Source: Ridge, 2009)

Another advantage of using synthetic line is that the stiffness and elasticity of the mooring line can be adjusted to ensure that the mooring line can be enhanced to allow less hydrodynamic effects acting on it. As being said in the previous section, stiffness is one of the parameters that may affect the hydrodynamic performance of a breakwater (see section 2.3.1). Thus the introduction of spring line as being studied by Chen *et al* (2001) will help to bring more stiffness factor in the mooring lines, thus helps it to perform accordingly.

2.5.2 Mooring Line Stiffness

The stiffness of mooring line will decide on the motion of the floating breakwater subjected to the wave movement, as well as the damping forces acted on the mooring line itself. Thus, it is important for us to find the correct mooring line tension in order to obtain the best stiffness line to get an efficient floating breakwater performance.

The stiffness of the mooring line might go down to the configuration of the mooring line system that being used, as both taut line and catenary mooring system gives different mooring stiffness value. Besides that, alternating the mooring line stiffness also might give us an advantage depending on the type of waves that are being considered throughout the process.

Loikogeorgaki and Angelides (2005) have done a study based on the effect of the mooring line stiffness of the hydrodynamics of the floating breakwater, as being shown in **Figure 2.7**. In the figure, the graph C1 denotes the base case of the study, which is at 0 pre-tension stresses and graph C2 denotes the variation in the tensile force with a pre-tensile stress applied to the mooring line. From the result, it is clear that the lines with a higher stiffness value produce a higher mooring tension. Thus, it can be said that there are considerable effects of the mooring line stiffness to the dynamic of the floating breakwater, in a sense that both the hydrodynamics motion and forces are being affected in the process. The effect of the mooring stiffness also can be found in the studies of Diamantoulaki and Angelidis (2011), Matulea *et al* (2008), Rahman *et al* (2006) and Gobat and Grosenbaugh (2001), in which all of these studies underline the significant impact of various mooring line stiffness to the hydrodynamics of the floating breakwater.

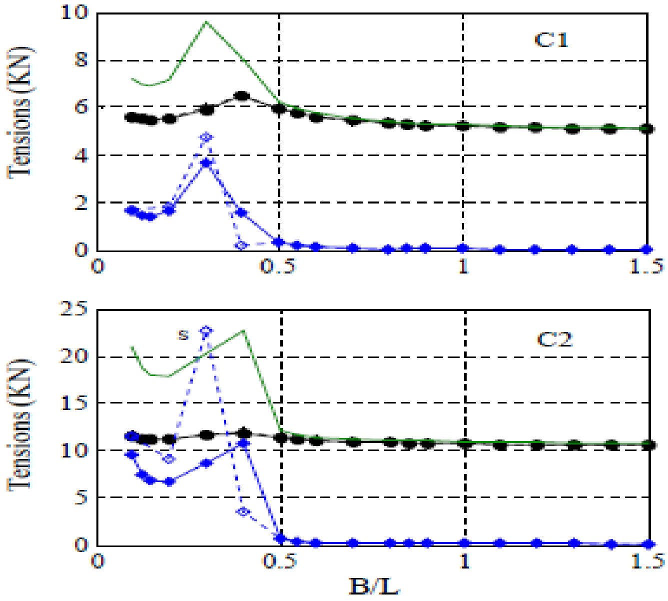


Figure 2.12: Variation of mooring line tension based on different stiffness (Source: Loukogeorgaki and Angelides, 2005)

2.5.3 Mooring Line Configurations

According to the study done by McCartney (1985), there are two ways to attach the breakwater and the lines of the mooring. The mooring lines can be attached either by straight configurations or by crossing the lines, as being shown in the **Figure 2.10**. The ways of attaching the lines to the breakwater may have an impact on the hydrodynamics of the breakwater, as it can restrict the movement of the floating breakwater. Keel clearance for boats moored alongside the breakwater can be provided by giving the breakwater a crossed line configurations. However, crossed line will also caused an increase in the heave and sway motion of the breakwater, subsequently affecting the performance of the breakwater. This theory is supported by a study done by Whiteside (1994). In the study, the effect of the position of the moored on the breakwater is also being studied. According to the study, by placing the mooring attachment points at the site of the breakwater, the sway motion can be restricted as compared to placing the attachment points directly at the bottom of the breakwater.

Sannasiraj *et al* (1995) also suggested that crossed mooring produced a higher transmission coefficient values and higher mooring forces. Thus, it is not advisable to use crossed moorings, as it will significantly affect the performance of the floating breakwater. Another mooring line configuration factor that can affect the performance of the hydrodynamics of the floating breakwater is the number of attachment points provided for the mooring. A more mooring attachment points on the breakwater will give the breakwater a more stable posture, in which restricted the sway motion due to wave's impact. Thus, this will directly give the floating breakwater a better wave transmission ability.

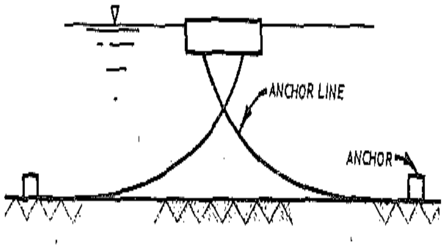


Figure 2.13 Crossed mooring lines

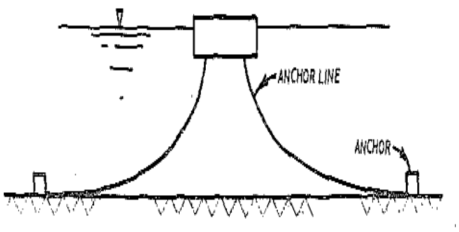


Figure 2.14 Uncrossed mooring lines

(Source: McCartney, 1985)

2.5.4 Length of Mooring Lines

The taut-leg moorings and the carternary mooring types are determined by the length of the mooring lines provided, as being discussed in section 2.3. The difference in the configuration does have an impact in the behavior of the floating breakwater, both in motion-wise and performance-wise. As being suggested by Whiteside (1994), the changes of the mooring line from slack to taut mooring give a less sway motion on the breakwater, subsequently reduced the mooring forces acting on the mooring lines. These hydrodynamic impacts will then contribute to the performance of the breakwater, as less movement and mooring forces acting on the line will increase the transmission efficiency of the floating breakwater

Apart from that, the length of the mooring lines will also affect the draft of the floating breakwater. As a result, the wave transmission ability will also be affected. When the draft or mass of the floating breakwater is being manipulated, it will affect the performance of the breakwater, especially on the sway amplitude. Thus, by varying the draft of the floating breakwater accordingly, we can adjust the sway amplitude and the damping resonance accordingly. A larger draft means that a larger momentum that will grow faster than the resistance, causing an increased in the resonance peak (Foursert, 2006). With an increasing width to the floating breakwater caused a decrease in the draft. This will lead to an increase in wave sway amplitude motion. Thus, in other words, we can say that the amplitude of the motion increases when the decrease of wave exiting forces is less than the decrease in the hydromechanical forces, and vice versa

The effect of such parameter has also been studied in previous past studies, such as in the studies by Murali and Mani (1997), Diamantoulaki *et al* (2009), and Hedge *et al* (2007). The results that have been yielded by these studies do inflicted that there are significant effects of the floating breakwater by changing the width and draft of the floating breakwater accordingly. This theory is also supported by He *et al* (2012), in which suggested that the increase in the draft of the floating breakwater will produce a less heave, surge and pitch motion up to certain extent.

2.6 Past studies on hydrodynamics of floating structure

In the recent years, there are various studies that have been done in understanding the hydrodynamics of the floating breakwater of various configurations. The hydrodynamics of the floating breakwater gives out different behaviour due to the changes of the configurations. There are several factors that may lead to the difference in terms of the behaviour of the breakwater. Thus, the goal of these studies being done is to obtain the most effective design, in which a minimal hydrodynamics behaviour is obtained, and in the same time, an effective performance is expected from the breakwater. Although it is near impossible to find the ultimate configurations of the floating breakwater behaviour, due to the fact that the subject itself is too subjective, but the combinations of various design together with its testing may give us another new set of point of view towards this matter

2.6.1 The effect of mooring lines

According to McCartney (1985), a moored floating breakwater should be properly designed in order to ensure effective reduction of the transmitted wave energy that leads to the adequate protection of the lee side of the floating structure, non-failure of the mooring lines, and non-failure of the floaters themselves and their interconnections. Loukogeorgaki and Angelides (2005) studied the performance of moored floating breakwater with respect to the effect of stiffness and damping of the mooring lines. There are several configurations consists of two types of conditions that have been examined in this experiment which is taut condition and slack condition. This has been done by modification of the length of the mooring lines that will affects the stiffness and drag damping of the mooring lines, and consequently, the effectiveness of the floating breakwater. The transition from the slack to the taut conditions results in a significant difference in the heave and sway response of the floating breakwater. Based on the experiment, the increase of the draft through reduction of the length of mooring lines leads to increase of their stiffness, which results in increase of the floating breakwater's effectiveness. Condition of taut mooring lines for configuration C3 and C4 indicates excellent performance compare to slack mooring condition for C1 and C2. Apart from that, the increase of mooring lines stiffness also leads to lower values of sway and heave response as the draft increases.

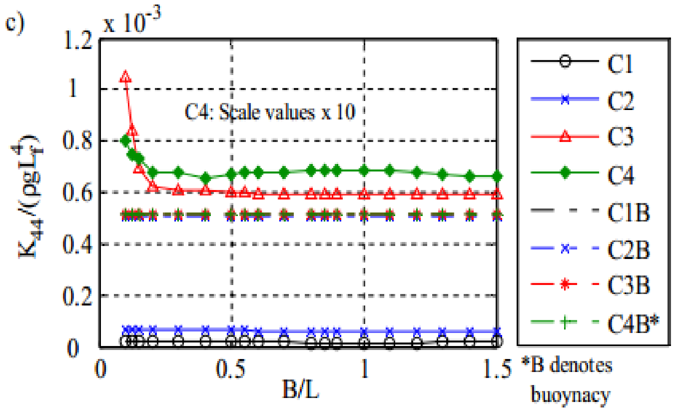


Figure 2.15: Stiffness coefficient as a function of B/L

The effect of the layout on the mooring forces of floating breakwaters under irregular waves would give significant effects towards the efficiency of the floating breakwaters. A significant increase of the design loads on the mooring lines would induce to choose different technologies which leads to additional costs. Besides that, extreme loads do not only effect the mooring system but may also effect the durability of the structure. Therefore, the overall performance and the evaluation of mooring forces are critical factors for the convenience of the installation of floating breakwater. One possible strategy that can improve the installation of floating breakwater is by align the breakwater obliquely with respect to the main wave direction or, more generally, by adopt more complex layouts.

A research to estimate the performance of a floating breakwater towards the oblique waves has been done by Ruol et al., (2008). In this experiment, an L-shaped layout is introduced and results are compared to the previous experiment done by Martinelli et al., (2007) where only the I-shaped and J-shaped layouts were examined. The study indicates that the moorings in the L-shaped configuration are loaded less compare to the I-shaped. This is due to the total exposure of the L-shaped layout of breakwater is smaller. However, the I-shaped induces less reflection, and more dissipations compared to other layouts. A final conclusion has been drawn from this experiments which is by increasing complexity (J-shaped and L-shaped) of the layout will increase the transmission, decrease the mooring forces and also increase the link forces.

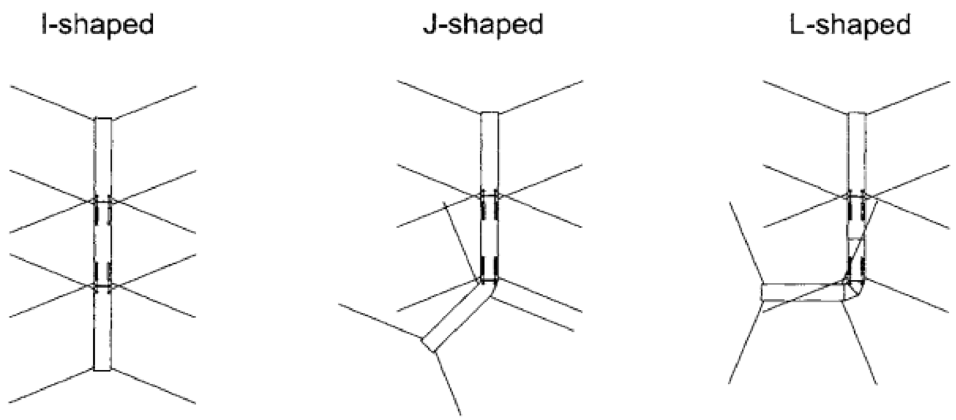
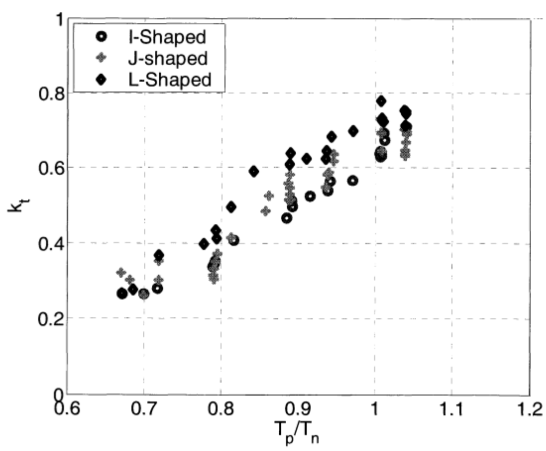


Figure 2.16: L-shaped, I-shaped and



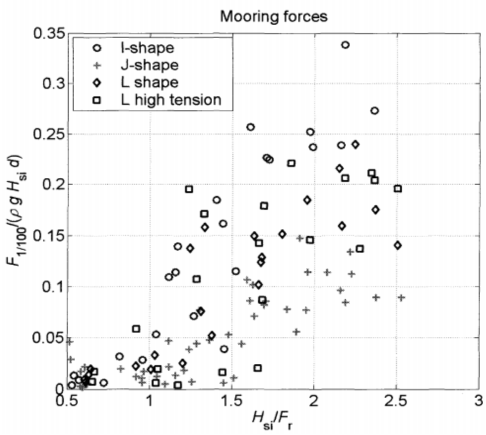


Figure 2.17: Transmission coefficient, Kt vs non-dimensional wave period

Figure 2.18: Max load on the mooring vs degree of overtopping

Apart from that, Ferreras et al. (2013) studied the effect mooring lines typology and layout upon the structural behaviour of a floating breakwater. Different elastic anchor stiffness levels and initial pretensions were analysed. The results revealed that mooring loads increased with both wave period and wave height for swell waves and they are therefore higher than those for sea waves. Low mooring line stiffness leads to a considerable reduction of static and dynamic loads.

2.6.2 Hydrodynamic performance of floating breakwaters

The studies of the hydrodynamic performance of a floating breakwater have been done by a lot of researchers. An experiment has been done in order to provide an economical way to improve the performance of box-type floating breakwaters for long waves without significantly increasing its weight and construction cost by introduced a new design of floating breakwater equipped with pneumatic chambers. Therefore, hydrodynamic performance of floating breakwaters with and without pneumatic chambers have been compared and investigated experimentally. In this study, it was found that by increasing the draught of the floating breakwater has reduced the surge, heave and pitch motions (He et al., 2012). This is due to the air pressure fluctuations inside the chambers decreased with increasing draught and for the long as well as very short period waves, the breakwater with a deeper draught was more effective in reducing the transmitted waves. Figure 2.11 shows the results obtained for the floating breakwater equipped with pneumatic chambers.

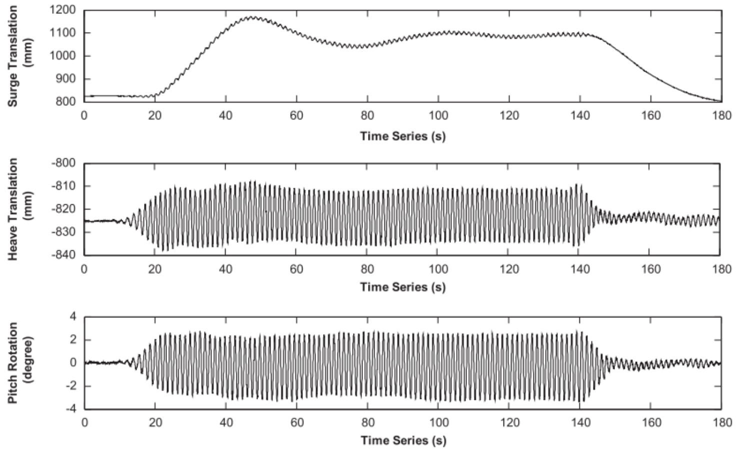


Figure 2.19: Sample temporal data of motions including surge, heave and pitch (He et al., 2012)

Apart from that, the study of a floating breakwaters as a dynamic wave at attenuating system has been done by Fousert (2006). In this study, ReFBreak model called Rectangular Floating Breakwater Design Model has been developed as a hydrodynamic mass-spring model as shown in figure 2.10. With this ReFBreak model, the motion for heave, sway and roll have been evaluated. He results shows that an optimal design for a small wave periods (<10s) has a large width/draught, while the design for long wave periods (>10s) should have a ratio close to one. Other than that, he also concluded that a screen is only valuable when small wave periods are considered.

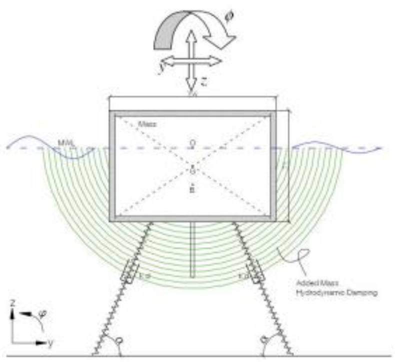


Figure 2.20: Hydrodynamic mass-spring system (Fousert, 2006)

2.6.3 Dynamic behaviour of floating offshore platforms

As the oil industry moves toward deeper offshore areas, considerable interest has been developed in the use of compliant structures, especially tension leg platforms (TLP), for exploitation of oil and gas from under seabed for processing.

Chandrasekaran and Jain (2002) studied on the dynamic behaviour of square and triangular shape of offshore tension leg platforms (TLP). The coupled response of a triangular TLP with that of a square TLP and the effects of different parameters that influence the response are investigated by Chandrasekaran and Jain (2002). At the end of this study, it is concluded that the square TLP exhibits a higher response in the surge and heave degrees of freedom compare to triangular TLP considered for comparing the response under a regular wave. However, the square TLP produces less forces in the pitch degree of freedom.

On the other hand, Teigen (1983) presented the response of a TLP in both long-crested and short-crested waves and he has concluded that the low-frequency part of the horizontal response looked enlarged in tests carried out in long-crested seas, compared to in short-crested seas.

Apart from that, OAA et al. (2008) studied the dynamic analysis of two typical types of spar platforms which is classic spar and truss spar. In this experiment, the motion responses of the floating platforms under different environmental conditions such as regular, random waves and current have been determined. There are three types of motion responses that have been evaluated which is surge, heave and pitch motion. Based on the study, the graph shows that truss spar gave higher responses than classic spar when subjected to random waves. However, as the truss spar is of much lower cost and as the responses are within the allowable limits for the platform design, truss spar is increasingly becoming popular nowadays.

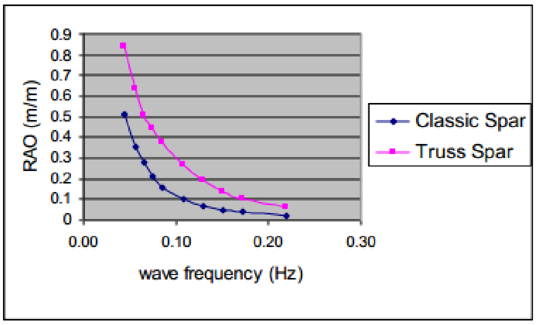


Figure 2.21: Surge response in random waves

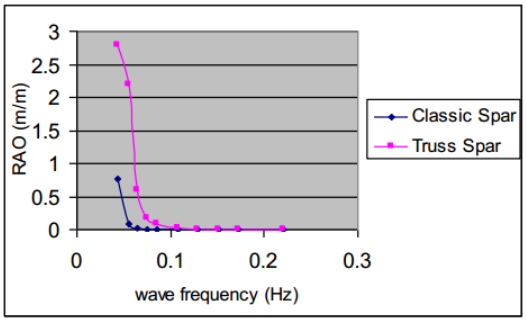


Figure 2.22: Heave response in random waves

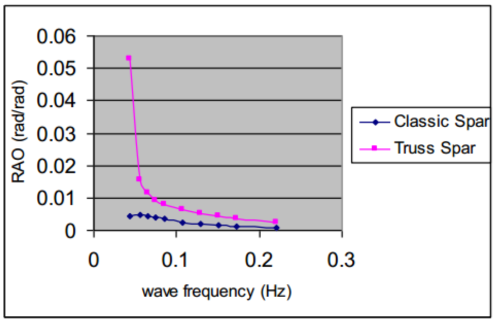


Figure 2.23: Pitch response in random waves

CHAPTER 3

METHODOLOGY

This chapter consists of the equipment and instrument that are involved during the experiment of the test model. The experiment will be carried out in the Offshore Laboratory situated in Block A at Universiti Teknologi PETRONAS (UTP). Besides that, this chapter will also discuss on the procedure in conducting the study and the planned gantt chart throughout the whole semesters.

3.1 H-Type Floating Breakwater (H-FLOAT)

H-Float model that has been scaled into 1:15 ratio will be test in this study. The design that is introduced for the study is a continuation from the past studies that has been done in the previous years by the seniors which is also UTP students. However, the breakwater will be enhance based on the previous design so that it will improve the efficiency of the breakwater. New configuration of mooring lines is also introduced in this experiment so that it will reduce the significant pitch motion that has been evaluated during the previous experiments. The changes that have been made towards the new design of breakwater model will contribute to the different sets of data as compared to previous study.

Figure 3.1: H-frame (before coating)

Figure 3.2: Fabricated test model

3.1.1 Model Description

In this study, an H-Float was developed according to 1: 15 model scale. As previous test model, the proposed materials that are to be used for this model are plywood, coated with fibre-glass coating which will act as water-proof membrane to the surface of the test model.

The general dimensions of the test model are 500 mm width x 1440 mm length x 250 mm height. The breakwater was constructed by plywood and was made waterproof by a layer of fiberglass coating on the surfaces of the body. Plywood is chosen as the primary construction material because it is a lightweight material that provides high resistance to external force impacts. The fiberglass coating was injected with yellow colouring pigment for better visibility of the model during experiment.

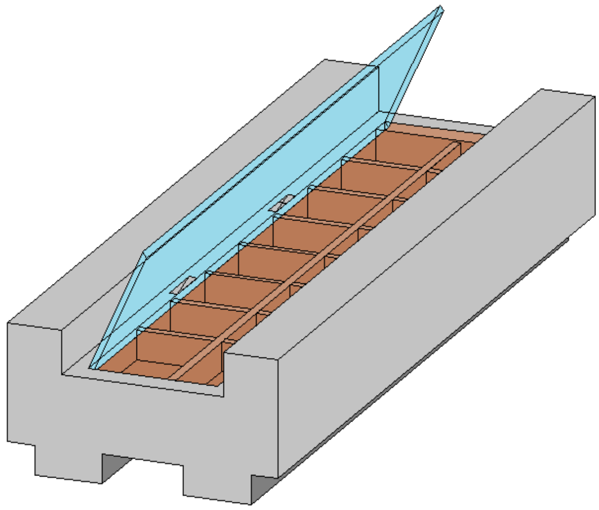


Figure 3.3: Isometric view of H-Float

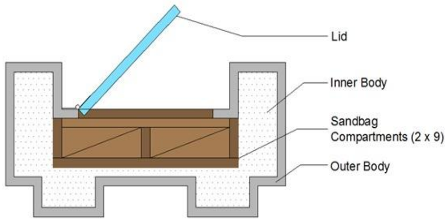


Figure 3.4: Typical section of H-Float

The breakwater has a pair of upward arms and a pair of downward legs, with both connected to a rectangular body. The seaward arm, body and leg act as the frontal barrier in withstanding the incident wave energy mainly by reflection. Some wave energy is anticipated to be dissipated through vortices and turbulence at the 90^o frontal edges of the breakwater. When confronted by storm waves, the H-type floating breakwater permits water waves to overtop the seaward arm and reaches the U-shape body. The overtopped water trapped within the U-shape body heavily interacts with the breakwater body, and the flow momentum is subsequently retarded by shearing stresses (frictional loss) developed along the body surfaces. The excessive waves in the U-shape body may leap over the shoreward arm and reaches the lee side of the floating body, making a new wave behind the breakwater which is termed as the transmitted waves.

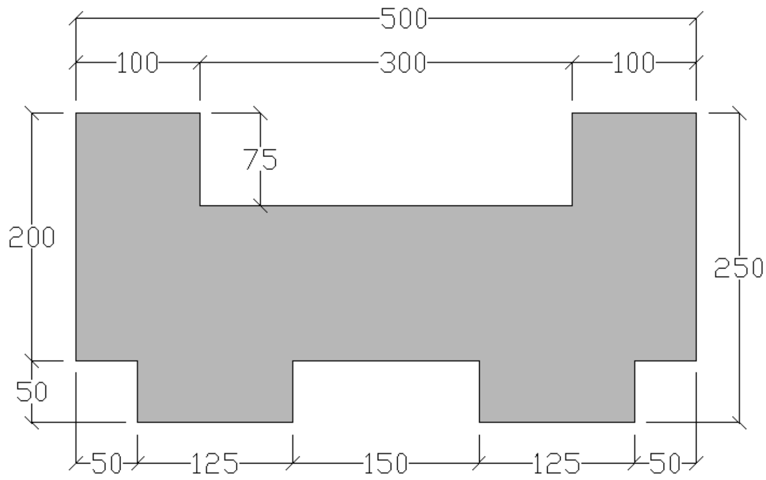


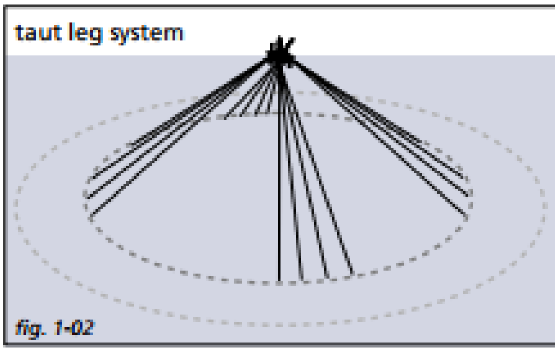
Figure 3.5: Side view of outer body

As breakwater immersion depth is an important parameter controlling the hydrodynamic performance of the floating breakwater, a ballast chamber located within the breakwater body was designed for adjustment of immersion depth of the breakwater with respect to still water level, in a freely floating condition. For the breakwater model, a 2 x 9 matrix wooden grid system was developed for the placement of sandbags for weight control of the breakwater. The ballast chamber was covered by transparent lid made of Plexiglas. The gap between the breakwater body and the transparent lid was tightly sealed by plasticine so as to prevent the seepage of water to enter the ballast chamber.

The sides of the floating body facing the flume walls were coated with polystyrene foams to prevent direct collision between the concrete wall and the fiberglass coated breakwater body. The implementation of the polystyrene foams at both sides of the breakwater would not pose significant disturbance to the movement of the floating body.

3.1.2 Mooring Systems

In this study, there are two different mooring configurations have been studied which is taut leg system and catenary system as shown in **Figure 3.6 and Figure 3.7.** Both of this mooring configurations have perform differently in order to limit the movements of the test model. By the taut leg system, the mooring cables terminates at an angle at the seafloor with minimal slack condition while for the catenary system the mooring cable terminates at the seafloor horizontally.



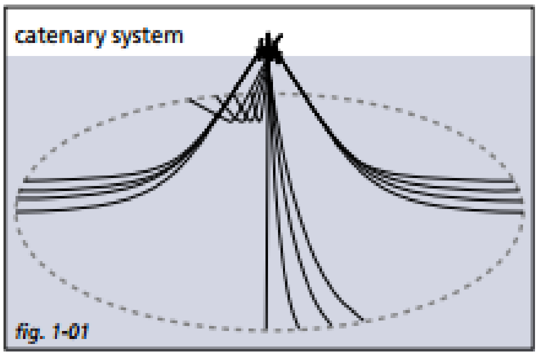


Figure 3.6: Taut Leg mooring system **Figure 3.7: Catenary mooring system**

For the taut leg system, there are eight mooring cables have been attached to the H-Float. This mooring system is chosen since it gives the test model up to six degree of freedom movement. Besides that, this mooring system is common used due to its advantages, which is shorter mooring line, more economical in deep water and has smaller footprints. However due to the small footprints needed for the taut-leg system, therefore strong anchor is needed. In taut-leg mooring system, the mooring line is connected in a straight line from the floating breakwater model to the anchor located at the floor of the wave flume. Such configuration will give the mooring line a pre-tensile stress prior to the test. The mooring line will be connected to the wall of the floating breakwater by means of hooking the end of the line to the designated hooking point on frame of the test model.

Whilst, for the catenary system there are four mooring cables have been attached to the model in a slack condition. These type of mooring required longer mooring cables and also bigger footprints. Based on the previous researches, this type of mooring will perform better during the storm compare to taut leg mooring that will easily breaks after the storm passed.

The H-frame that consist of eight hooks at the bottom of the frame will be attached to the breakwater model. Eight different points beneath the breakwater model will be moored by the test model for the taut leg mooring system while four different points beneath the breakwater model will be required for the catenary mooring system. Each of the attached hooks beneath the breakwater was tied by using a thin metal rope with low elasticity while the other end was attached to the floor of the wave flume. The purpose of having the hooks attached to the frame is to avoid the damage of the floating breakwater. Besides that, there are more number of hooks that can be applied due to these frame rather than directly attached the hooks at the wall of the test model like the previous experiment. Therefore, other than strengthen the test model, this new configuration also will avoid excessive movement experienced by the test model due to the increase in the number of mooring lines which induce more stable position towards the test model. Such mooring configuration will help to avoid the test model from overturning.

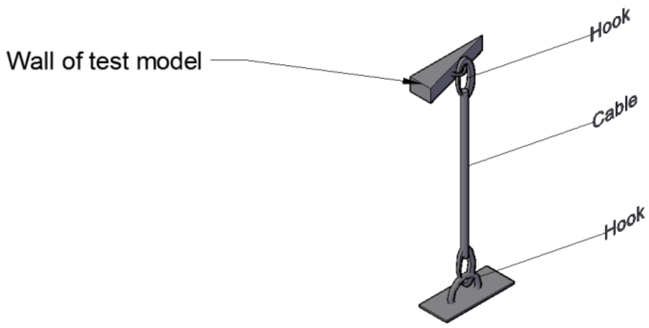


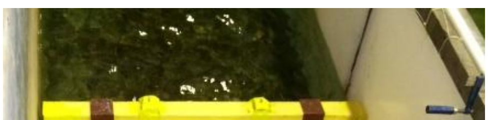
Figure 3.8: Configuration of mooring system for test model

As far as the mooring system is concerned, this will be the first time such effect of mooring configurations on motion responses of the H-Float will be studied. Thus, the previous studies by other researchers will be used as benchmarked to the study. A greater movement by the test model will also be expected, together with a higher force on the mooring line, due to the pre-tension configuration; as compared to the previous studies by the other students. In order to hook the test model with the floor of the wave flume, a thin metal rope with low elasticity was tied to each hook beneath the breakwater and the other end was attached to the floor of the wave flume.

3.2 Laboratory Equipment and Instrumentations

3.2.1 Wave Flume

A series of experiment are to be conducted in a 25 m long, 1.5 m width and 3 m high wave flume as shown in the Figure 3.8. The maximum permitted wave depth in the flume is up to 1.2 m. The walls of the wave flume are made of reinforced concrete, with 6 transparent flexiglasses located at both side of the wave flume. The



purpose of providing these glasses is to easily monitor the test models during the experiment

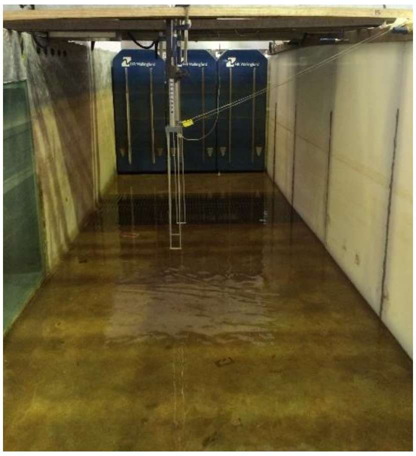


Figure 3.9: Wave Flume **Figure 3.10: H-Float in the wave flume**

3.2.2 Wave Paddle

A wave paddle is installed at the one end of the wave flume and is used to generate waves to mimic the real sea condition. The wave paddle is able to generate both regular and irregular waves in the flume. It is powered by a single motor generator, with a capability of generating waves up to 2 second wave period, and maximum wave heights of 0.3 m. The wave paddle was manufactured by the Edinburgh Design Ltd., United Kingdom. The wave paddle actively absorbs the reflected waves in the flume through the use of a force feedback system. The control of the wave paddle is operated using ocean and wave software supplied by Edinburgh Design Limited. To generate waves in the wave flume, command signals coded using WAVE program needs to be properly compiled to facilitate the computation of a wave elevation time series corresponding to the desired state.

Figure 3.11: Wave paddles

3.2.3 Wave Probes

Six wave probes were used in this experiment in order to measure the incident wave height, reflected wave height and transmitted wave height in the flume. Three of the wave probes were placed before the test model while another three were placed after the test model. This is in accordance to the 3-point method (Mansard and Funke, 1980). **Figure 3.12** shows the probes being arranged in a straight line perpendicular to the model and the wave paddle. The maximum measurement of wave height is 0.4m and 128Hz for wave frequency. Calibration of probes was done prior to conducting any tests to avoid any measurement errors.

The probes facing the wave paddle were used to measure the incident and reflected wave heights, while the probes at the lee side of the model were meant to measure the transmitted wave height and the reflected waves from the wave absorber (if any). Data obtained from the wave probes were used for calculation to separate the incident and reflected wave spectra from the co-existing wave spectra by using the 3-points method developed by Mansard and Funke (1980). This method is based on least square analysis and is far superior to the 2nd point method in regards of frequency range, sensitivity to noise and lesser deviation or distraction from the linear theory.

Figure 3.12: Wave probes

3.2.4 Wave Absorber

At another end of the wave flume, a wave absorber is placed to absorb the remaining wave energy from the incident waves generated by the wave flume. As a requirement, the wave absorber must be made up of a material that can absorb up to 90% energy from the incident waves. This is to avoid any reflection from the waves that may alter the values of the subsequent waves, which may affect our readings.

Figure 3.13: Wave absorber

3.2.5 Optical Tracking System (OPTITRACK)

Optical tracking system called OPTITRACK is used in order to record the hydrodynamic motion responses of the test as shown in **Figure 3.14**. OPTITRACK is attached at the side of wave flume. This tracking system is able to detect all 6 degree of movements of an floating object during the testing process using 3 units of camera that capture the image of the reflective balls (as shown in **Figure 3.15**) located at the top of the test models.

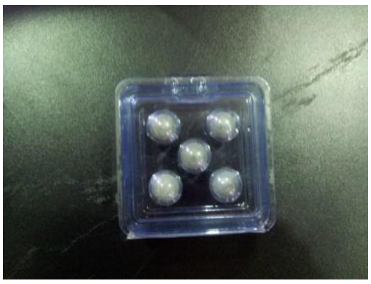


Figure 3.14: OPTITRACK **Figure 3.15: Reflective balls**

3.2.6 Experimental Set up

Figure 3.16 shows the experimental set-up and the location of each equipment and instrument. The test model was located at the mid-length of the wave flume, which is 4 m apart from the wave paddle. The test model is anchored to the floor of the wave flume by the means of metal cables and hooks. The mooring system will be attached to a roller at the bottom of the wave flume, and the end of the mooring line will be attached to the wall of the wave flume. This is to ensure that the pre-tensile stress of the mooring line can be controlled easily without having to alter the mooring line configuration from inside of the wave flume.

The reflective balls are put on top of the test model. The movement of these balls, which is equivalent to the movement of the model, was captured by three optical tracking cameras located at close proximity of the model. These cameras located on the top of the wave flume's wall at close proximity of the model.

Three wave probes were located both seaward and shoreward of the model for the measurement of water level fluctuation at the respective locations. These time series data were then further analysed using computer tools to yield some significant wave parameters, e.g. significant wave height, peak wave period, etc. Mansard and Funke's method (1983) was adopted to decompose the wave signals from the three probes into incident and reflected wave components. To achieve this, the probes were carefully arranged according to the spacing requirement set by Mansard and Funke (1980).

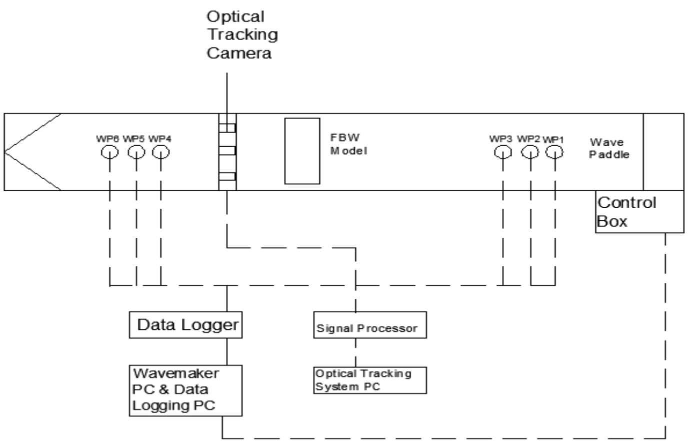


Figure 3.16: Experimental Set-Up

3.2.7 Experiment Configuration

As being discussed in the previous chapter, the equipment that were used in this study were set-up inside a wave flume, which will generate the required wave conditions throughout the testing. The testing of the floating breakwater model will be done as planned, with four different water drafts, a number of distinguished wave periods and wave steepness of random and regular waves were being tested in order to study the effect of these drafts to the movement of the model as far as the RAOs are concerned. The full experiment configuration is illustrated in **Figure 3.17** below.

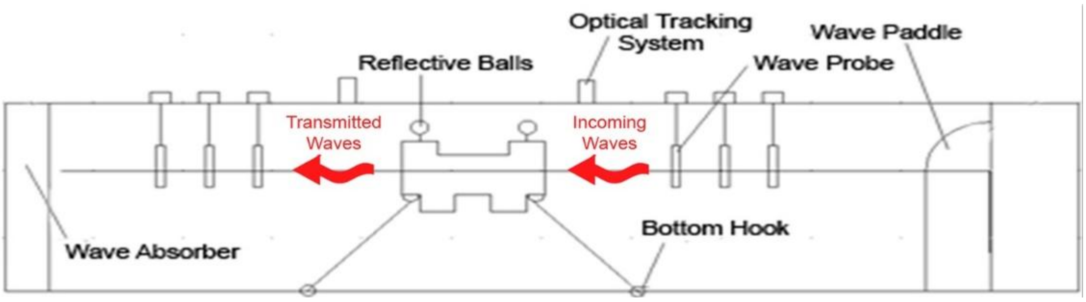


Figure 3.17: Experiment Configuration

3.3 Experimental Test-Run

In testing the test model, the behaviour of the H-Float model under different sets of condition is to be monitored. Thus, all the fixed and manipulated parameters that will be tested are to be established. The variables that are going to be used in these experiments are listed in the table 3.1.

Fixed Variables	Dependant Variables
Model orientation	Wave period, t
Water depth, d	Significant wave height, (Hs)

Breakwater draft, d	Mooring configurations

Table 3.1: Variables used in the testing

In each of the dependant variables, the values of each parameter are varied. Noticed that in each mooring configurations, the test model will be tested at different wave period, which is at 0.2 second interval. Furthermore, in each wave period, the H-Float will be tested at different wave height, corresponds to the H/L values. It is worth to note that in this study, hydrodynamic responses of the H-float in random waves is crucial as the test environment resembles the irregularity of the real seas. The number of runs that was conducted throughout the testing is shown in Table 3.2.

Breakwater Draft, D (m)	Water depth, d (m)	Mooring Configurations	Wave Periods, t (s)	Wave Steepness, H/L
0.15	0.73	Taut Leg	0.8	0.04
				0.05
				0.06
			1.0	0.04
				0.05
				0.06
			1.2	0.04
				0.05
				0.06
		Catenary	0.8	0.04
				0.05
				0.06
			1.0	0.04
				0.05

				0.06
				0.04
				0.05
			1.2	0.06

Table 3.2: Test Parameters

3.4 Project Management

In the first half of the study, the focus is more on the introduction and preparation towards the further study. Besides that, observation on experiment also being done for the existing model conducted by previous student. This help to understand how the experiment is being conducted so that in near future, the experiment can be conducted as efficiency as possible. Gantt chart will help this study in keeping track of the progress and proceed accordingly. In the Gantt chart, feasibility of the study will ensured as it is initially planned in the beginning of the study and task will be cleared. The Gantt chart includes time element to the respective project activities. This is to ensure that the study can completed within the given time frame, which is 2 semester. The Gantt chart for the whole project is given in **Figure 3.18.**

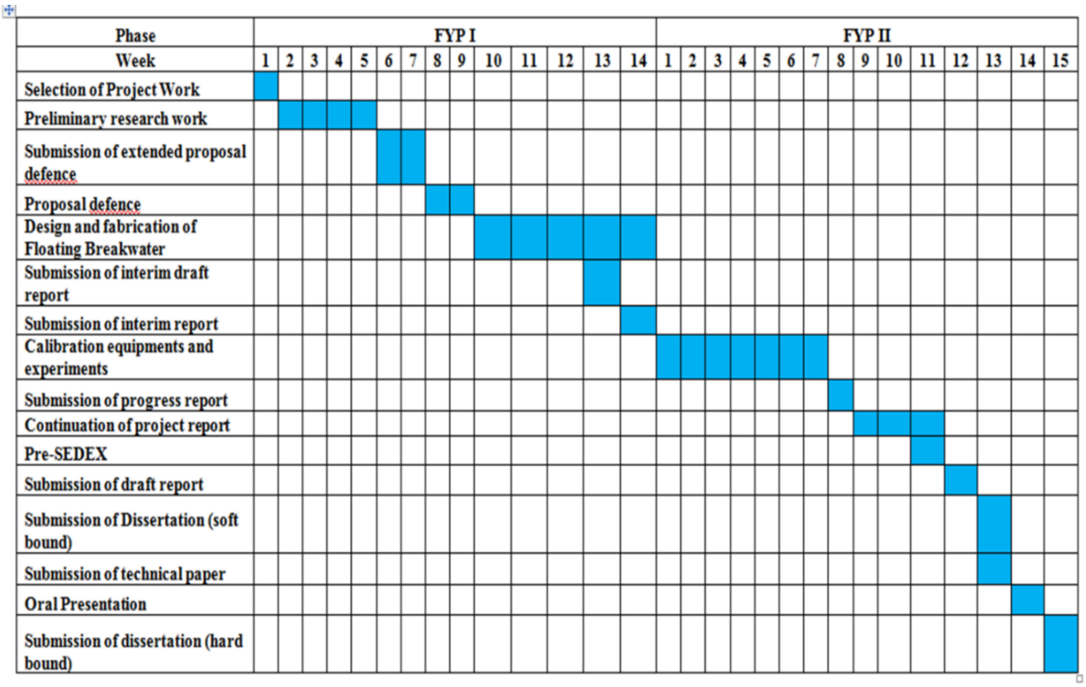


Figure 3.18: Gantt chart

Key milestone show the program of the existing study against the planned work schedule. By the time of the writing, the floating breakwater is in fabrication.

So far, the research about the scale effects has been studied, and how the experiment is being conducted also being observed from the project conducted by previous student.

In completing the studies, a series of activities need to be done in order to ensure the feasibility of the study. These set of tasks are done in a number of stages in order to ensure the unobstructed flow of the study. The flow chart of the research activities is given in **Figure 3.19.**

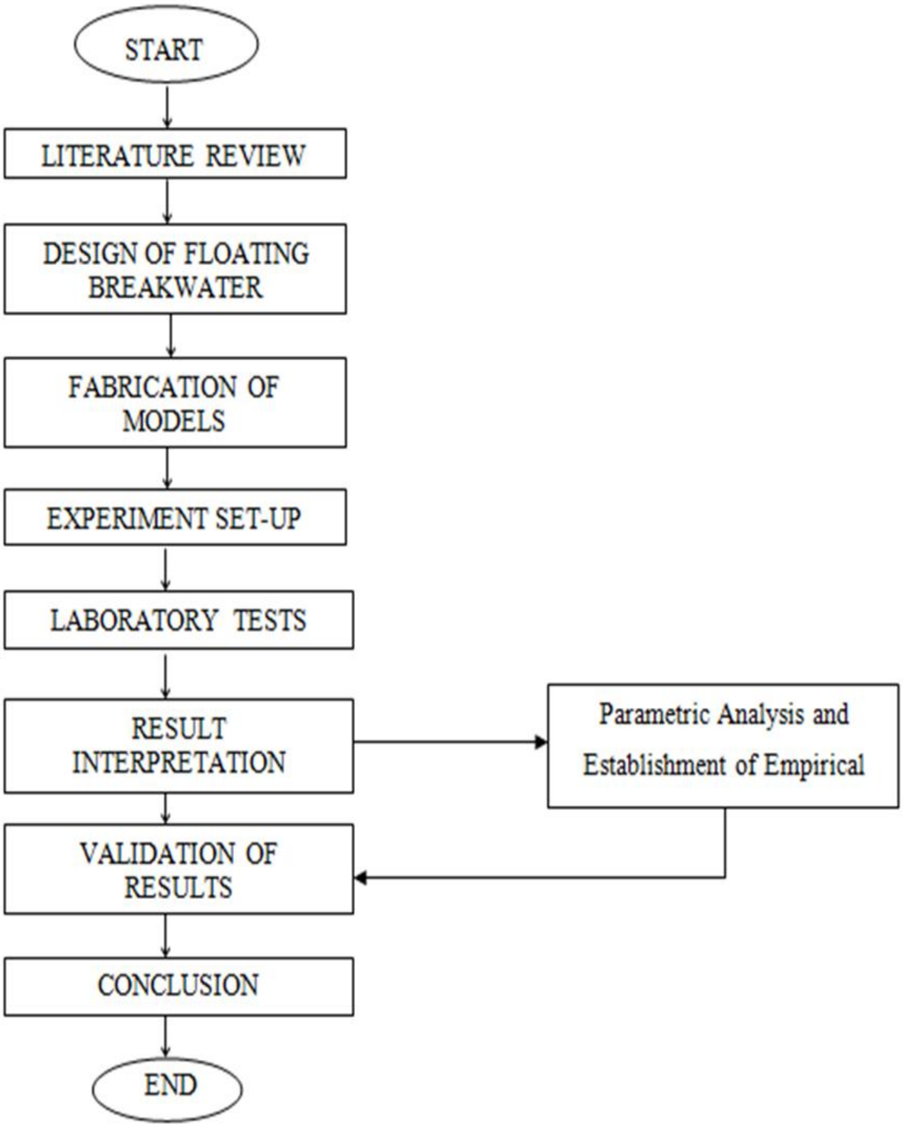


Figure 3.19: Project activities

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter presents the measured motion responses of the H-Float in the forms of time series and frequency domains for each set of experiment conducted in the wave flume. These analyses are particularly important in providing better interpretations of the results in the later stage of the study. The details of the analyses are to be thoroughly discussed in this chapter. The motion responses (*i.e.* heave, surge and pitch) of the breakwater model are presented in respective Response Amplitude Operators (RAO). A parametric analysis is also conducted to give a complete representation of all the experimental tests that were carried out in this study, and some key conclusions are drawn at the end of this chapter.

4.1 Calibration of Wave Probes and Wave Flume

The calibrations of the wave probes and wave flume will be done by using the three-point method proposed by Mansard and Funke (1985). The significant of this method is to measure simultaneously the waves in the flumes at three different points with an adequate distance between one set of probe to another. The wave probes were located parallel to the wave's direction in the wave flume. **Figure 4.1** shows the set-up of the wave probes in a wave flume. The Probe 1 the wave paddle is denoted as X1, the length of Probe 1 to the Probe 2 is denoted as X12 and the length of Probe 1 to Probe 3 is denoted as X13.

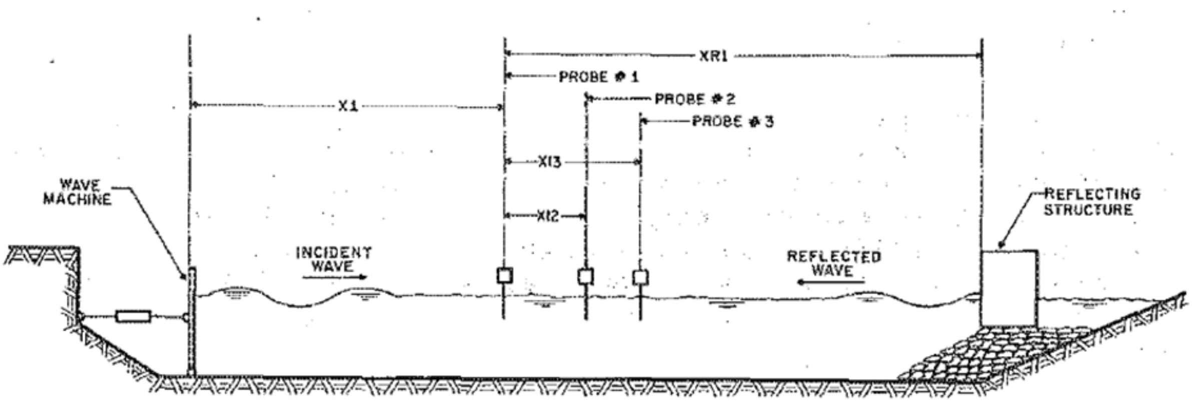


Figure 4.1: **Three-point method calibration set up (Mansard and Funke, 1985)**

The proposed spacing between the probes set by Mansard and Funke (1985) are as follows:

X12 = Lp/10 Lp/6 < X13 < Lp/3 X13 ≠ Lp/5 and X13≠3Lp/10

where Lp is the wavelength corresponding to the peak wave period. The importance of following the spacing requirement as stated in the study is to ensure that there are no singularities in the wave probe readings. The spacing of the wave probes corresponding to the wave periods are shown in **Table 4.1** below.

T(s)	L_p (m)	f (Hz)	Distance of probe 1 to 2 (cm)	Distance of probe 2 to 3 (cm)	Distance of probe 1 to 3 (cm)
0.8	1.00	1.25	10.0	13.0	23.0

1.0	1.55	1.00	15.5	28.0	43.5
1.2	2.17	0.833	20.0	28.0	48.0

Table 4.1: Wave probe spacing

This study was carried out against random waves to simulate realistic sea condition rather than simulating a controlled environment with regular wave condition. To program specific wave height in the wave generation software, a zero run was first carried out in an empty flume in a series of trial and error with various gain values to obtain the real gain value for that specific water depth. This gain value is considered an important tool in generating specified wave height accurately and must be done prior to each study with varying water depth and experimental setting. It is not advisable to reuse gain value that are more than few months old as the efficiency of the wave paddle may have decline since then and as a result, the aptitude may varies.

Table 4.2 shows the corresponding gain value for each wave height that was obtained from the gain value tests.

Wave steepness H/L	0.04		0.05		0.06	
T(s)	Wave Height (m)	Gain Value	Wave Height (m)	Gain Value	Wave Height (m)	Gain Value
0.8	0.04	1.22	0.05	1.21	0.06	1.21
1.0	0.06	1.30	0.08	1.30	0.09	1.30
1.2	0.09	1.30	0.11	1.30	0.13	1.40

Table 4.2: Gain value for corresponding wave height and steepness in random waves

4.2 Measured Results

Series of experiments were rigorously conducted in the wave flume to study the motion responses of the H-Float moored by taut leg system and catenary system in random waves. It is worthwhile to mention that only heave, surge and pitch motions are measured whilst the sway, roll and yaw motions are restricted due to the limitation of the equipment in the laboratory. These motions were recorded by an optical tracking system (OPTITRACK) operated by 3 high speed cameras. The present experiments considers a wave type (random waves), three wave steepness (*i.e.* H_i/L = 0.04, 0.05 and 0.06) and two mooring configurations which is taut leg system and catenary system. Nevertheless, some tests involved high steepness waves could not be carried out in the wave flume due to mechanical restriction of the wave paddle.

The motions of the H-type floating breakwater are often quantified by the Response Amplitude Operators (RAO), which is amplitude of motion relative to the wave amplitude. Higher RAO values indicate greater motion response at the degree of freedom, and vice versa. This section presents some samples of raw data and the related analyses of the data. Note that it is not possible to display the above results of all the tests conducted here as these will overload the thesis. The measured data were first observed using time series analysis and the characteristics of the data were subsequently assessed by the frequency domain analysis.

4.2.1 Time Series Analysis

The time series signals of heave, surge and pitch motions of the H-type floating breakwater subjected to random waves of H_i/L = 0.04 are respectively plotted in a 50-s window with a start-up time of 0 s, as shown in **Figure 4.2**. It can be observed from the plots that the motion signals of the model become highly irregular, in which the amplitude of the waves are in a less uniform manner and are difficult to be quantified in time series manner.

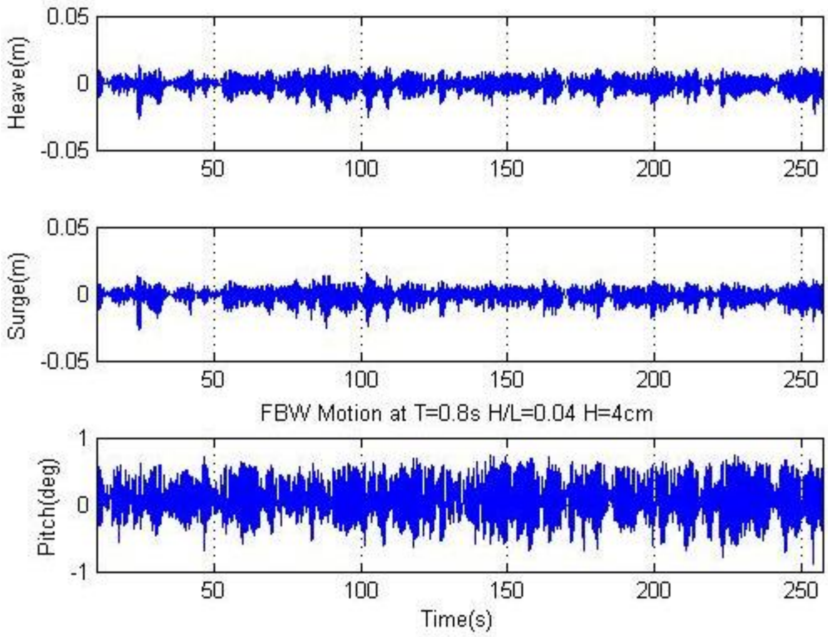


Figure 4.2: Time Series graph for (i) heave, (ii) surge and (iii) pitch responses for H/L = 0.04, and frequency = 1.25 Hz subjected to random waves

4.2.2 Frequency Domain Analysis

The characteristics of the regular signals might be feasibly and sufficiently evaluated using time series analysis. However, the characteristics of the irregular signals can only be identified by transforming the time series data into a frequency domain, where the *x*-axis appears in the form of frequency, *f* (unit: Hz) and the *y*-axis appears to be an energy density, $S(f)$ (unit: m^2s). For this study, the use of JONSWAP spectrum was utilized in the conversion of the time series analysis graph into frequency domain analysis graphs.

Figure 4.3 shows the corresponding spectral energy densities of the time series signals for heave, surge and pitch motions of the H-type floating breakwater. For the case of random waves, an inverted bell shape curve is distributed across the frequency domain whereby signals of various periods/frequencies and amplitudes are observed and the peak of the curve refers to the peak frequency of the motion mode. For instance, a significant energy density peak can be observed in all of the motion response graphs for heave, surge and pitch in frequency domain analysis. However, whilst the peak is positioned almost at the same frequency as the natural period of the incident waves, the spectral energy peak for random waves are less obvious, with the existence of some other energy spectral readings at both lower and higher frequency than the natural frequency of the incident waves.

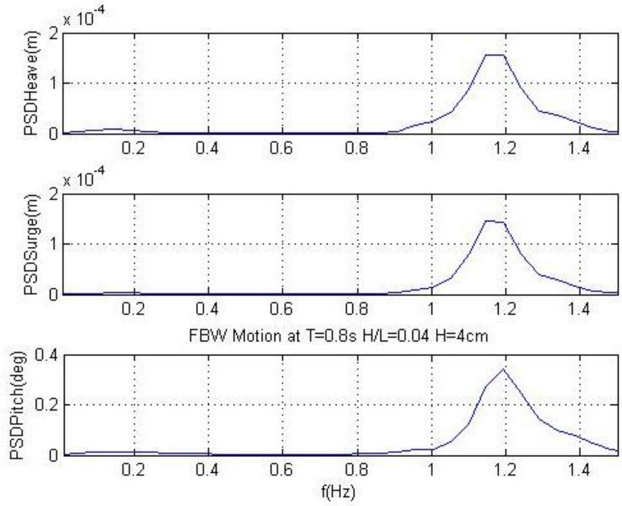


Figure 4.3: Energy Spectral Density graphs for (i) heave, (ii) surge and (iii) pitch responses for H/L = 0.04, and frequency = 1.25 Hz subjected to random waves

4.3 Result Interpretation

Section 4.2.2 presents the variations of RAO in frequency domains for the H-Float subjected to random waves. The RAO-peaks of the entire tests were recorded and evaluated based on the relative breakwater width, *B/L*, which is one of the most accepted design parameter for breakwaters. The RAO results for heave, surge and pitch motions of the test model moored by taut leg system and catenary system in random waves of H_i/L = 0.04, 0.05 and 0.06 are to be thoroughly discussed in the following sections.

4.3.1 Response Amplitude Operators

In order to quantify the movement of the floating breakwater model with respect to the wave action acting on the model, a dimensionless parameter is used for the study. The dimensionless parameter, known as Response Amplitude Operator (RAO) defined as the motion response of the floating body per wave height amplitude. In the study, the motion response of the floating breakwater based on the energy spectral density with respect to the wave energy acting upon the floating breakwater model were being considered. This study will only considered the three degree of freedom for the floating body, namely the heave, surge and pitch responses due to the limitations of the apparatus and equipments. Thus, the formula used to calculate the RAO for heave, surge and pitch motion is defined as follows:

$$RAO_n({}^{m}/_{m}) = \sqrt{\frac{S_{f,motion}}{S_{f,wave}}} \qquad (4.1)$$

Where RAO_n is the RAO response of the floating body (n= heave, roll, pitch), $S_{f,motion}$ is the amplitude of motion spectral energy response and $S_{f,wave}$ is the wave energy amplitude based on the spectral energy density graphs.

4.3.2 Heave

This experiment has been conducted in two different mooring configurations which is taut-leg and catenary mooring systems. **Figure 4.4** shows the peaked heave RAOs for the H-Float moored by taut-leg mooring while **Figure 4.5** shows the peaked heave RAO's for the H-Float moored by catenary mooring. The H-Float subjected to random waves of three different wave conditions which is H/L=0.04,0.05 and 0.06. The test model was immersed for 0.15m breakwater draft in 0.73m water depth.

Based on the results, the heave RAOs for the H-Float moored by both taut leg and catenary systems decrease with an increase of *B/L*. This implies that the heave motion of the test model increase with the increasing period of the incident waves. This is sensible because the size (*i.e.* the width) of the breakwater is relatively small compared to the wavelength, and consequently the breakwater tends to move along with the incoming waves. This is due to high wave periods induce more developed waves which cannot be resist by the test model. The results shows that the H-Float is a reasonably good in short period waves. On the other hand, the breakwater has more resistance towards smaller waves with shorter wavelength due to its higher effective mass in the water.

However, the taut leg mooring system which is so rigid has induce low motion responses of the H-float compare to catenary system. This is sensible because of the limited length of the taut leg mooring which has been connected in a straight line with minimal slack condition compare to catenary system which is in high slack condition and cause it to move considerably. For the taut leg system, the mooring cables have been attached bidirectional by using eight mooring cables which is higher compare to catenary that is used four mooring cables. Therefore, the results has been expected due to the strength of the mooring cables for taut leg which is more stable and cause it to restrict the motion of the test model.

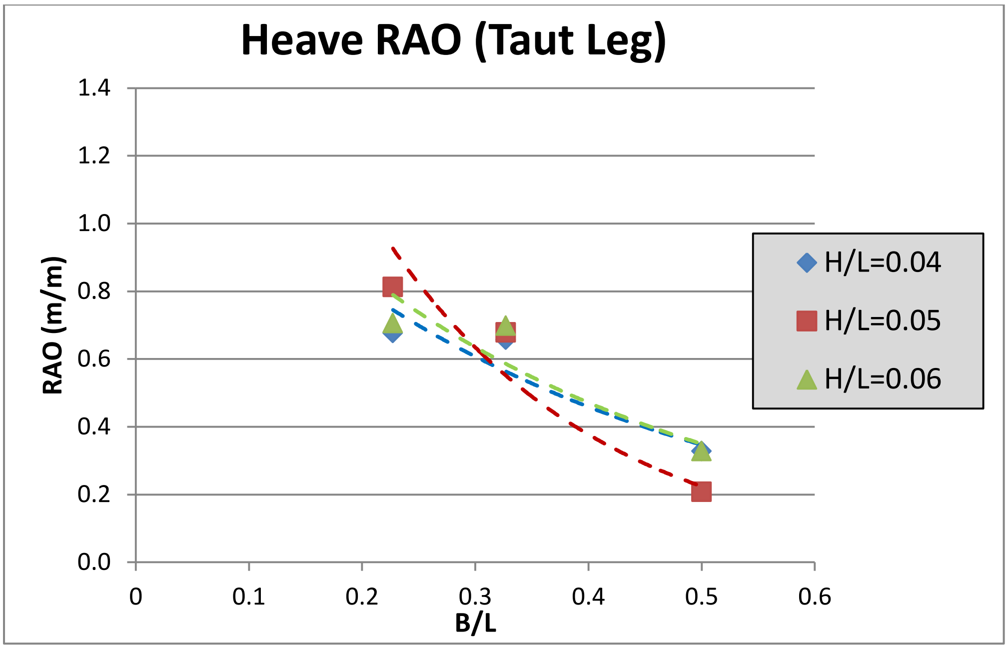


Figure 4.4: Peaked heave-RAOs of the H-Float moored by taut leg system in random waves

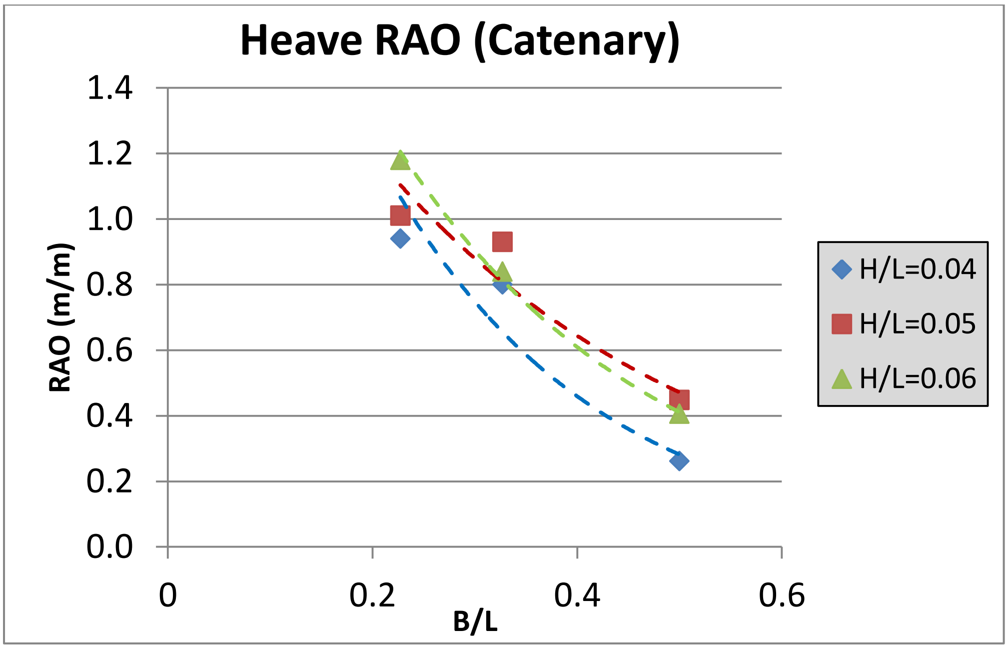


Figure 4.5: Peaked heave-RAOs of the H-Float moored by catenary system in random waves

4.3.3 Surge

The peaked surge-RAOs of the H-Float moored by taut leg and catenary mooring system which is exposed to random waves derived from the frequency domain analysis are shown in **Figures 4.6 and Figure 4.7**. Based on the graphs provided, the surge-RAOs for both taut leg and catenary systems shows that the effect of wave steepness are particularly minimal since it is overlapped each other.

Figure 4.6 indicates that the surge-RAOs for the H-Float moored by taut leg decrease with the increasing *B/L* when subjected to random waves environment. This can be explained by the fact that the surge motion of the floating structure is strongly governed by the advancing wavelength, *i.e.* the greater the magnitude of the wavelength, the larger will be the surge response of the breakwater.

On the other hand, the H-Float moored by catenary system shown by **Figure 4.7** indicates that the surge-RAOs increases with the increasing of B/L. This implies that the surge motion of the test model moored by catenary system increase with the increasing frequency of the incident waves. As the frequency increases it will induce high scope due to pounding effects towards the H-Float and cause it to move considerably.

In comparison with the taut leg mooring system, the surge RAOs for the H-Float moored by catenary system are much higher. The finding is expected since the catenary system induce higher scope due to the pounding effects towards the H-Float that makes it to moves considerably. While for the taut leg mooring system, the mooring cables of the test model has restricted the H-Float from surging further. The four mooring cables for catenary system which have been attached to the test model were in a slack condition. Whenever the test model move to the front, it will pull the mooring cables at the back together with the front movement and make it to be in a straight condition with a minimal slacks. The slack condition of this catenary mooring system will cause the test model to move further compare to taut leg system which is in a straight condition.

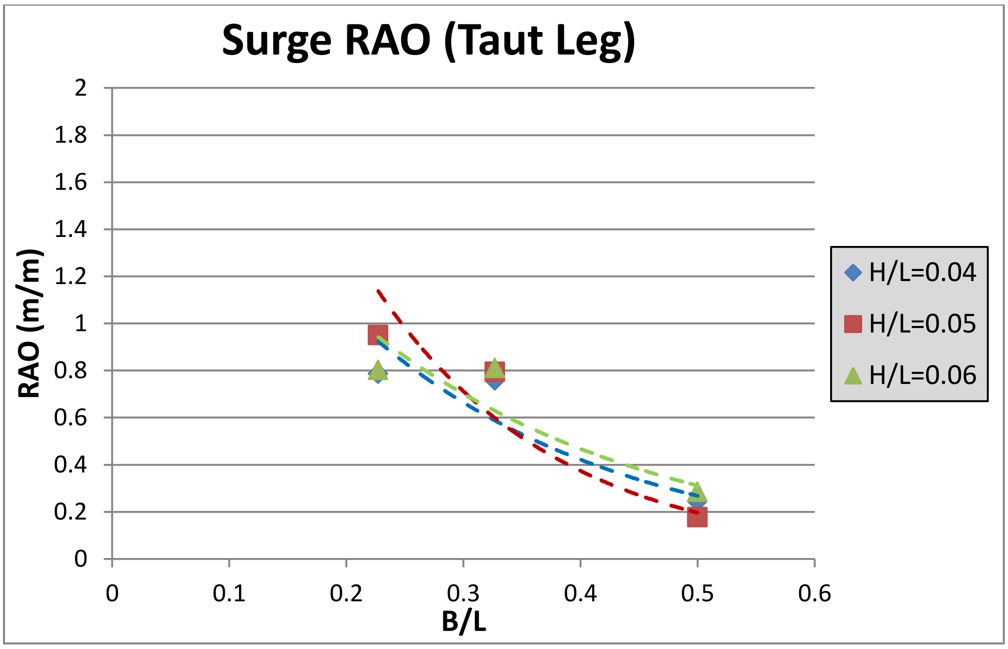


Figure 4.6: Peaked surge-RAOs of the H-Float moored by taut leg system in random waves

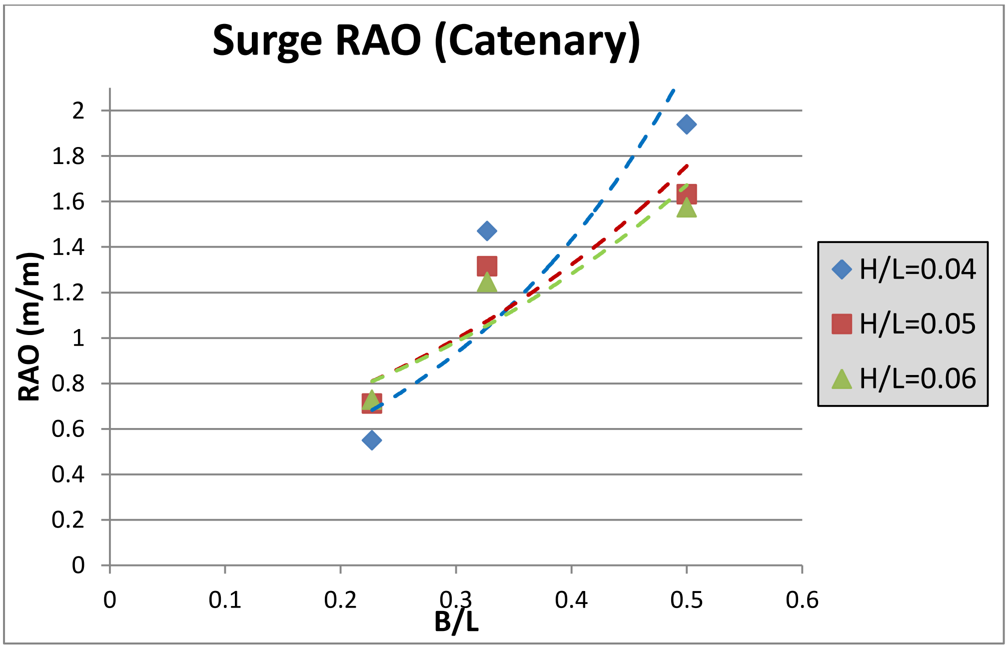


Figure 4.7: Peaked surge-RAOs of the H-Float moored by catenary system in random waves

4.3.4 Pitch

The pitch-RAOs of the H-Float moored by different mooring configurations subjected to random wave environments are demonstrated in **Figure 4.8 and Figure 4.9**. It is noted from both figures that the pitch-RAOs for the taut leg system is lower compare to the catenary system. This is due to the rigid condition of the taut leg mooring configuration which restraint the movement of the test model. While the slack mooring cables of catenary system will induce high movement of the H-Float when subjected to random waves.

The pitch-RAOs for the H-Float moored by taut leg system shows that the pitch-RAOs decreases with the increasing of B/L at harsher wave conditions (Hi/L=0.05 and 0.06). This implies that the pitch motion of the test model increase with the increasing period of the incident waves. This is due to high wave periods that will produce more stable waves and caused an increase in number of wave overtopping onto the limited freeboard of the test model, i.e. the waves overtop the crest of the test model which results in clockwise rotation (pitch). However, at the mild wave condition (H/L=0.04), the pitch RAOs carried no specific pattern and less predictable.

As far as the changes pattern for the pitch-RAO is concerned, it is worth to note that the pitch-RAOs for the H-Float moored by catenary system carried no specific pattern with the changes in the B/L and the wave period. It is rather scarce and is considered to be less predictable. Therefore, further research has to be conducted in order to reduce the significant pitch motion for this H-Float.

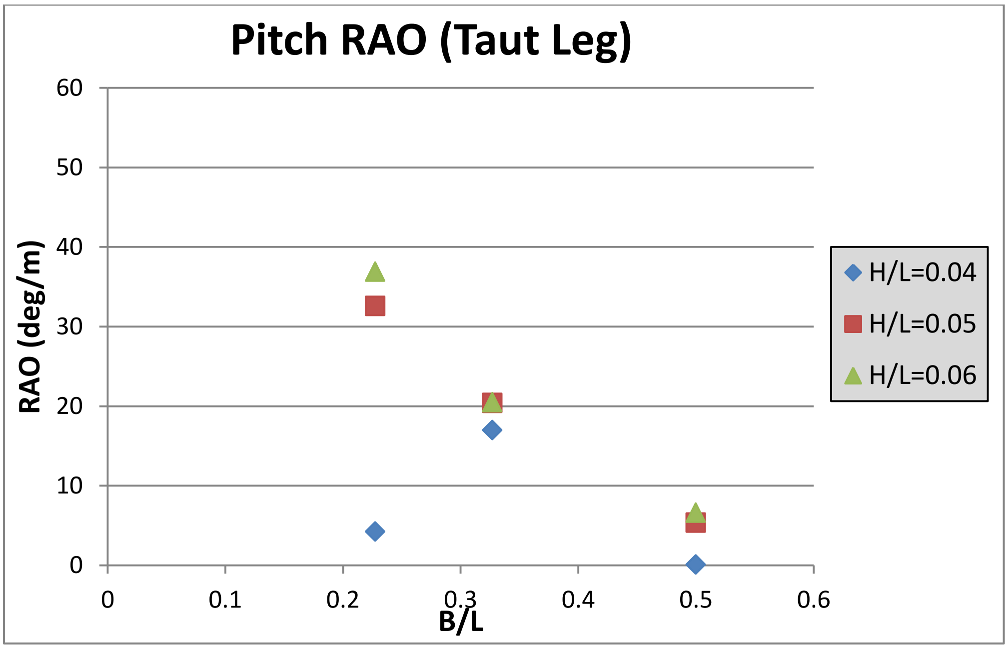


Figure 4.8: Peaked pitch-RAOs of the H-Float moored by taut leg system in random waves

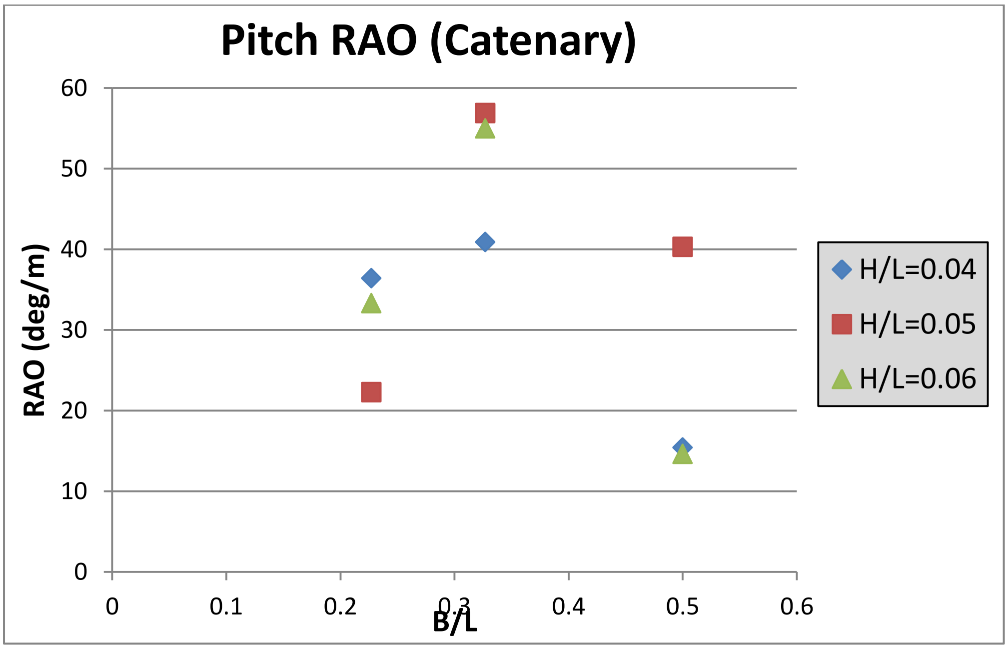


Figure 4.9: Peaked pitch-RAOs of the H-Float moored by catenary system in random waves

4.4 Concluding Remarks

The study of effect of mooring configurations on motion responses of the H-Float is important in understanding the movement behaviour of the structure when subjected to different wave conditions. This information serves as a basis or reference to the floating breakwater design in which the performance is not merely based on the structure configurations. The raw data of the existing experiment were evaluated by both time series and frequency domain analyses, for which the peaked-RAOs for heave, surge and pitch were identified numerically. These data were subsequently represented in a dimensionless design graphs for the ease of interpretation. The RAOs for heave, surge and pitch of both mooring configurations are summarized in the **Table 4.3**

Response Amplitude Operators (RAOs)	Taut Leg system	Catenary System
RAOheave	0.21-0.81 (low)	0.26-1.18 (high)
RAOsurge	0.18-0.95 (low)	0.55-1.94 (high)
RAOpitch	0.10-36.9 (low)	14.6-56.9 (high)

Table 4.3: RAOs for heave, surge and pitch motion

Based on the results, it was found that the H-Float moored by taut leg system is more hydraulically efficient, while catenary system shows higher RAOs results in significant motions and deterioration of hydraulic performance when subjected to random waves. Pitch response of the breakwater is another important aspect to be considered in the design of the mooring lines to the H-type floating breakwater if wave overtopping is allowed. The motion responses in terms of RAO obtained from this study will help to provide valuable information, especially in the design of the mooring connection of the breakwater. Each RAO values obtained in the study carried a unique representation on the motion responses and the wave actions based on different set of conditions of the floating breakwater. The heave, surge and pitch RAOs can be used to predict the respective motion responses of the floating breakwater given the particular wave conditions.

CHAPTER 5

CONCLUSION AND FUTURE ACTIVITIES

This chapter conclude the overall findings of this study and the completion of objectives. Recommendations for future study are included to ease potential future researches.

5.1 Conclusion

The analysis that has been conducted throughout this study has yielded a few major conclusions. These are the conclusion that can be made based on the end products of the study:

- The motion responses of the floating breakwater vary significantly with the changes in the mooring configurations. This is clearly shown in the RAO results that have been obtained in the study, particularly of heave and surge RAOs. Higher RAOs results in significant motions and deterioration of hydraulic performance of the H-Float moored by catenary systems in the random waves.
- As the wave period increases, causing a decreased in the wave frequency, the motion of the floating breakwater can be seen significantly increasing. The increased in the motion responses particularly can be observed through the increasing values of the RAO recorded based on the study. The increment in the wave period caused a higher energy within the wave system, in which causes more vigorous movement of the floating breakwater. The trend is recorded in all three degree of motions, regardless of the water draft.

- The effect of wave steepness are particularly minimal in both heave and surge RAOs, especially at more severe wave condition (*H/L* = 0.05 and *H/L*= 0.06). The difference of the heave and surge RAOs at higher wave steepness is considered to be very minimal. However, in the case of pitch RAO, the effect of wave steepness for all the three cases that have been tested (*H/L* = 0.04, 0.05, 0.06) is appeared to be very significant. Both heave and surge RAO have a definite trend with respect to the changes in the system, as far as the breakwater draft and the wave period are concerned. As for pitch RAO, no definite trend can be observed with respect to the changes, with the motion responses are acting in a less predictable manner.
- The usage of RAO can help to predict the motion responses of the floating breakwater with respect to the wave actions. Each motion responses will give different RAO value and this is clearly shown in the data obtained from this study.
- The RAO values obtained in this study is rather significance in providing information in the design of the mooring configurations of the H-Float. The RAO of motion response of heave, surge and pitch obtained in this study will help the designer in predicting the behaviour of the floating breakwater in real sea and thus, help to decide on the optimum mooring configurations for the H-type floating breakwater depending on the wave conditions of the sea state.
- The experimental procedure carried out in this study has shown some promising end products on the response of the H-type floating breakwater with respect to wave actions. The study has also met its primary objectives in investigate the effect of mooring configurations on motion responses of the H-Float in random waves. It can be concluded that based on the results, the H-Float is more hydraulically efficient when moored with a taut leg system compare to catenary system when subjected to random waves.

5.2 Recommendations

The recommended activities that can be done in the future in order to enhance further potential of the study are given as follows:

- The study of the forces in the mooring lines can be done in order to study the effect of the mooring lines towards the motion responses of the floating breakwater. The mooring lines recorded data, coupled with the data obtained from this study, will produce a valuable information which will assist in the design of the floating breakwater in real life applications
- In order to verify the potential of the system used in the study, a separate study of the H-type floating breakwater moored with other several types of mooring configurations can be done. Such study considered to be helpful, as comparison of the motion responses and the performance of the floating breakwater can be evaluated in order to obtain an optimum configurations for the H-type floating breakwater
- The scale effect study of the H-type floating breakwater can be done in the future. This piece of information will help in further verifying the RAO values obtained from this study and tested on the effect of scaling of the testing to the RAO values
- The study can be repeated at a bigger scale by using bigger facilities, such as wave tank, and better equipment with better capabilities. An upgraded version of the study can be done by fully obtained all of the 6 degree of freedom responses and their RAOs due to various wave conditions. The response of the mooring lines during the testing can also be recorded in order to study the hydrodynamic forces acting on the mooring lines for a more advanced analysis of the data.
- The mooring line has to design such a way that it can withstand very large waves and can last longer.

CHAPTER 6

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